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# Advanced Work in **AIRCRAFT RADIO**

*NAVPERC 10814 4th Ed.*



**1945** EDITION



## NAVY TRAINING COURSES





# ADVANCED WORK IN AIRCRAFT RADIO

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## PREFACE

This book is written for the enlisted men of Naval Aviation. It is one of a series of books designed to give them the necessary information to perform their aviation duties.

A knowledge of advanced work in aircraft radio is of primary importance to Aviation Radiomen and Aviation Radio Technicians. But they should approach this book only after they are thoroughly familiar with the material contained in **FUNDAMENTALS OF ELECTRICITY and AIRCRAFT RADIO EQUIPMENT**. That material provides a background for understanding advanced work in aircraft radio.

The book starts off with a study of Kirchoff's laws, measurement instruments, and the theory of a.c. Then come chapters on vacuum tubes, amplifiers, power supplies, and transmitters. Modulation and antennas are taken up next with a study of radio waves. Receivers, microphones, and oscilloscopes finish up the study of radio.

As one of the **NAVY TRAINING COURSES**, this book represents the joint endeavor of the Naval Air Technical Training Command and the Training Courses Section of the Bureau of Naval Personnel.

(III)

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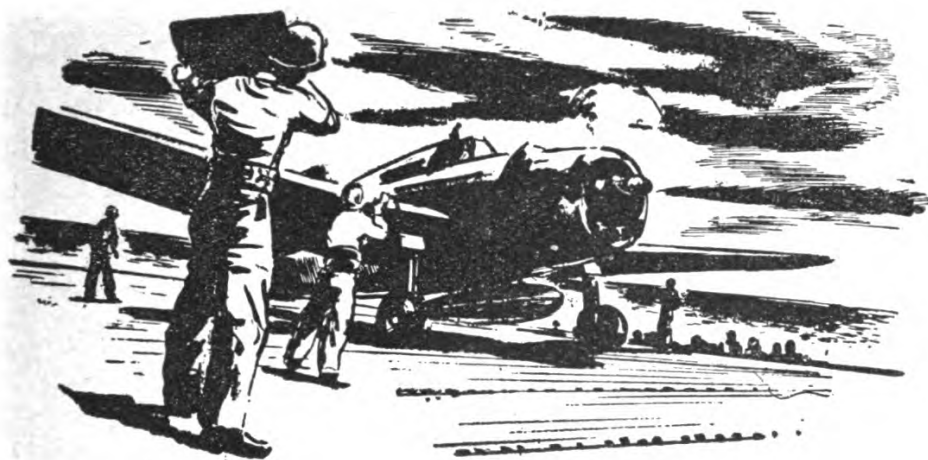


# ADVANCED WORK IN AIRCRAFT RADIO

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## CHAPTER I

### KIRCHOFF'S LAWS

#### AROUND THE CIRCUIT

In many electrical circuits, you'll find that the arrangement of the devices and applied voltages makes it almost impossible for you to solve such networks by simple applications of Ohm's Law. You can simplify these problems by the application of KIRCHOFF'S LAWS.

Here are the laws.

IN ANY ELECTRICAL NETWORK, THE ALGEBRAIC SUM OF THE CURRENTS THAT MEET AT A POINT IS ZERO.

IN ANY COMPLETE ELECTRICAL CIRCUIT, THE SUM OF ALL THE EMF'S AND ALL THE VOLTAGE ( $IR$ ) DROPS, TAKEN WITH THEIR PROPER SIGNS, IS ZERO.

#### FIRST LAW

Because the current in all parts of a SERIES circuit is the same, the current flowing AWAY from any given point in that circuit is equal to the current flowing INTO it. In other words, you get out just what you put in.

Look at figure 1. Use  $A$  as a focal point. You can see that the total current ( $I_1 + I_2 + I_3$ ) is the value of the current flowing to that point. The current flowing away from  $A$  in the direction of point  $C$  is  $I_1$  and that flowing in the direction of point  $B$  is  $I_2 + I_3$ . Therefore, the current flowing AWAY from point  $A$  equals that flowing TO it. The current flow-

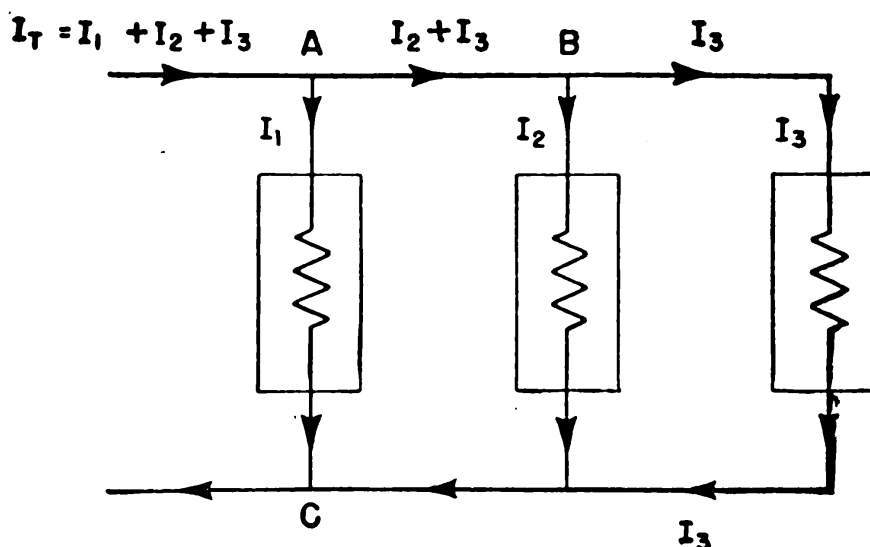


Figure 1.—Currents at a junction point.

ing TO a given point in a circuit is POSITIVE. Hence, current flowing AWAY from that point is NEGATIVE. In a practical application of the law as stated,  $I_1 + I_2 + I_3 - I_1 - I_2 - I_3 = 0$ . This law is true for any point in the circuit.

## SECOND LAW

Select some starting point in the circuit and follow a particular path around this circuit to the starting point. You will meet several voltage CHANGES. These changes are caused by voltage sources in the circuit and the IR voltage drop across any resistance in the circuit. In some cases, the change will be a voltage rise. In others, it will be a voltage drop.

The voltage across a battery and the IR drop across a resistor have polarities. Suppose you assign a PLUS

sign to each voltage RISE and a MINUS sign to each voltage DROP. According to KIRCHOFF'S SECOND LAW, the algebraic sum of these voltages, when added with proper polarity signs, is always zero. Be sure you understand the following problems—

### SAMPLE PROBLEM NO. 1

You have a battery with an emf of 6 volts and an internal resistance of 0.10 ohm connected to a load circuit whose resistance is 9.9 ohms. Find the load current.

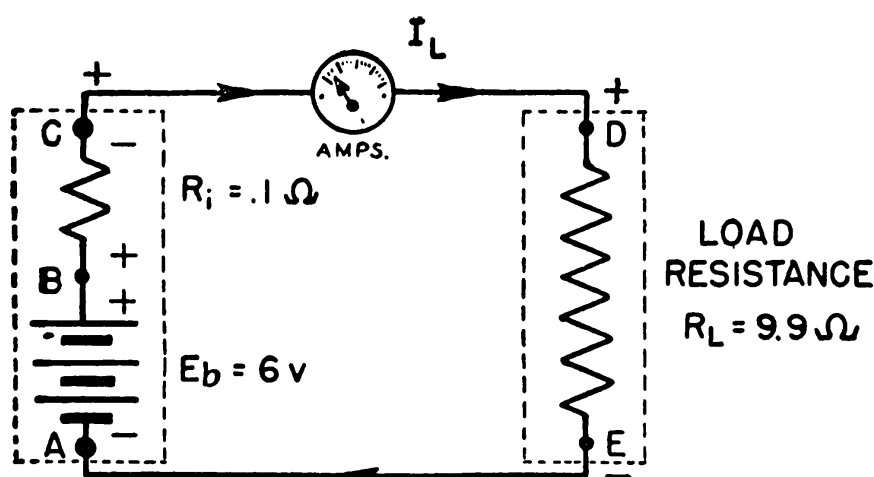


Figure 2.—Schematic diagram,—sample problem No. 1.

The schematic diagram for this problem is figure 2. Of course, you COULD use a simple application of Ohm's law to get the answer. But in this case, you can also use Kirchhoff's laws to get the answer. Let's use Kirchhoff for this one.

Start at point *A* and pass around the circuit in a clockwise direction. A voltage increase occurs in passing across the battery. Because a voltage drop occurs across the internal resistance  $R_i$  of the battery whenever load current  $I_L$  flows, you must write down the battery emf  $E_b$  between points *A* and *B* and the  $I_L R_i$  DROP between points *B* and *C*.

So that you can substitute these values in an equa-

tion, you must consider the polarity of each voltage change. Point *B* is positive with respect to point *A*. Hence, the value of battery voltage substituted in the equation will be a positive number. In this particular circuit, the load current flows from *B* to *C*, and *C* is negative with respect to *B*. The voltage drop substituted in the equation will be a negative number.

If the wires have very little resistance, there will be no voltage drop from *C* to *D* and these points will have the same potential, or electrical pressure.

In passing across the load resistors  $R_L$ , the last drop in voltage occurs. You get this voltage drop by multiplying the load current by the load resistance,  $E = IR$ . You must also consider this drop a negative number since point *E* is negative with respect to point *D*.

Again if the wire leading back to *A* has very low resistance, you can neglect this voltage drop and consider point *E* to have the same potential as point *A*. And you are back at the starting point.

The algebraic addition of these voltage drops must always equal zero. Apply this law and you can solve for the load current, which in this case you do not know. Here's the general equation for the simple circuit of figure 2:

$$\begin{aligned}
 E_{(A \text{ to } B)} + E_{(B \text{ to } C)} + E_{(C \text{ to } D)} + E_{(D \text{ to } E)} + E_{(E \text{ to } A)} &= 0 \\
 + E_b \quad - I_L R_i \quad + 0 \quad - (I_L R_L) \quad + 0 &= 0 \\
 \text{or } E_b - I_L R_i - I_L R_L &= 0
 \end{aligned}$$

Substitute the known values in the equation, and you get a simple equation with one unknown, the LOAD CURRENT  $I_L$ .

$$\begin{aligned}
 6 - .1 (I_L) - 9.9 (I_L) &= 0 \\
 6 - 10 I_L &= 0 \\
 I_L &= 6/10 = .6 \text{ ampere}
 \end{aligned}$$

Here are THREE POINTERS to help you apply this law to other problems—

### FIRST POINTER

In the more complicated problems, you can't always determine the direction of the current. So simply ASSUME A DIRECTION OF CURRENT FLOW. Just say to yourself, "It flows in THIS direction." If your assumption is backwards, your answer for current strength will be numerically correct, but will be a NEGATIVE number. Then you say to yourself, "The correct direction of current flow is in THAT direction. I guessed wrong."

### NEXT POINTER

PLACE POLARITY MARKINGS on ALL batteries and resistors in the circuit. The assumed current direction will not affect the battery polarities. But the voltage drop on resistors will be affected. And be sure you mark the voltage drops so that the resistor end at which current enters is positive. The other end, of course, will be negative.

### LAST POINTER

By working your way around the circuit, SET UP EACH TERM OF THE EQUATION. Include all voltage sources and all voltage drops. In the equation, precede each term by the sign found on LEAVING each particular battery or resistor.

Figure 3 is like figure 2 EXCEPT that the current is assumed to flow in the OPPOSITE direction. Start at A. Pass around the circuit in a counterclockwise direction—the same direction as the ASSUMED current flow. Follow the rules and you obtain each term of the new equation.

In passing from point *A* to point *E*, you do not have to consider any voltage drop. In passing from



point  $E$  to point  $D$ , write the first term of the equation as  $I_L R_L$  and take the last sign on leaving this point. This makes the first term  $(-I_L R_L)$ . As you pass from point  $C$  to  $B$ , the second term becomes  $-I_L R_i$ . Again you take the sign at the end of the resistor as you leave. In going from  $B$  to  $A$  the last term becomes

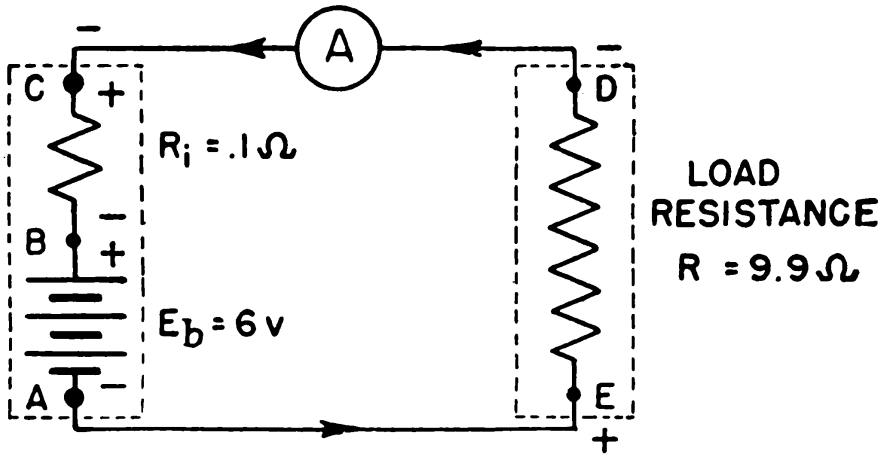


Figure 3.—Schematic diagram, problem No. 2.

$-E_b$ . Writing the terms in this same order and making them equal to zero, you get the following equation:

$$\begin{aligned} -R_L I_L - R_i I_L - E_b &= 0 \\ -9.9 (I_L) - .1 (I_L) - 6 &= 0 \\ -10 I_L &= 6 \\ I_L &= -6/10 = -.6 \text{ ampere} \end{aligned}$$

The answer is NEGATIVE. So the ASSUMED direction of current flow was REVERSED.

### SAMPLE PROBLEM NO. 3

A generator with an internal resistance of .01 ohm and an induced emf of 14 volts is connected through a series resistor to a battery having an emf of 12 volts and an internal resistance of .03 ohm. The series resistor has a value of .01 ohm. Determine the charging current.

The circuit diagram for this problem is in figure 4.

The generator has a higher voltage, hence you can assume that the current will flow as shown by the arrows. After this assumption, you can insert the electrical polarity of voltage drops on all resistors. By starting at *A* and passing around the circuit in

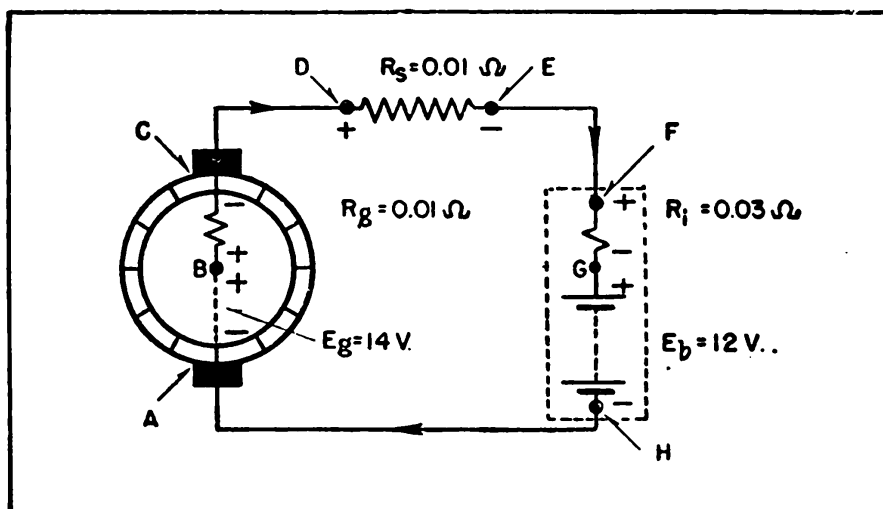


Figure 4.—Schematic diagram, and sample problem No. 3.

the direction of the current, you can write the general equation—

$$(A \text{ to } B) \quad (B \text{ to } C) \quad (D \text{ to } E) \quad (F \text{ to } G) \quad (G \text{ to } H) \\ +E_g - I_L R_g - I_L R_s - I_L R_i - E_b = 0$$

Substitute known values—

$$14 - I_L (.01) - I_L (.01) - I_L (.03) - 12 = 0$$

$$14 - .05 I_L - 12 = 0$$

$$- .05 I_L + 2 = 0$$

$$- .05 I_L = -2$$

$$I_L = \frac{2}{.05} = 40 \text{ amperes}$$

#### SAMPLE PROBLEM NO. 4

A load circuit with a resistance of 0.15 ohm is connected in parallel with a generator and battery. The induced emf of the generator is 28 volts and its armature resistance is 0.2 ohm. The battery has an

emf of 24 volts and an internal resistance of 0.1 ohm. Find (a) the terminal voltage of the battery, (b) the terminal voltage of the generator, (c) the current through the load circuit, (d) the current through the battery circuit, and (e) the current supplied by the generator.

You have the circuit diagram in figure 5. ASSUME the current direction shown by the arrows in the

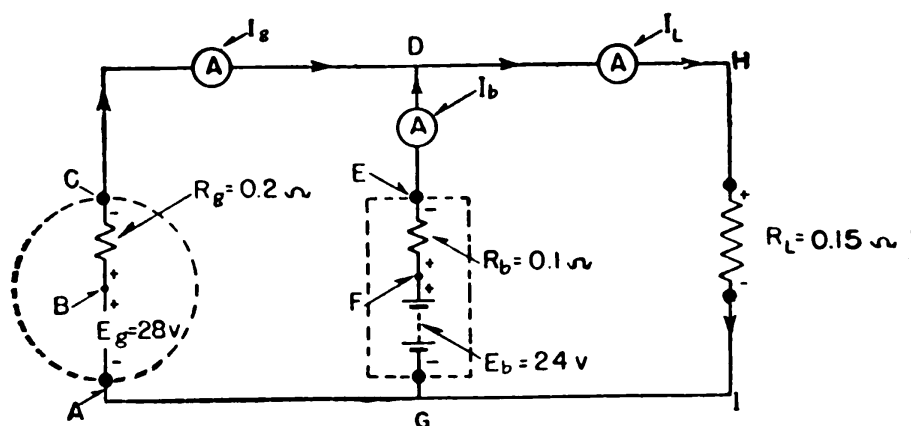


Figure 5.—Schematic diagram, and sample problem No. 4.

figure. Starting at  $A$  and going around the short path  $A, B, C, D, E, F$ , to  $G$ , and back to  $A$ , you can write the equation—

1.  $E_g - I_g R_g + I_b R_i - E_b = 0$
2.  $28 - I_g (0.2) + I_b (0.1) - 24 = 0$
3.  $4 - I_g (0.2) + I_b (0.1) = 0$

By starting at  $G$  and passing around the other path,  $G, F, E, D, H, I$ , you can form the next equation—

4.  $E_b - I_b R_i - I_L R_L = 0$
5.  $24 - I_b (0.1) - I_L (0.15) = 0$

By considering the currents flowing TO and AWAY from the JUNCTION,  $D$ , you can write—

6.  $I_g + I_b = I_L$

By substituting the term  $(I_g + I_b)$  for  $I_L$  in equation 5, you get—

$$7. \quad 24 - I_b(0.1) - (I_g + I_b)0.15 = 0$$

$$\text{or } 24 - 0.1I_b - 0.15I_g - 0.15I_b = 0$$

$$8. \quad 24 - 0.25I_b - 0.15I_g = 0$$

Equations 3 and 8 both have  $I_g$  and  $I_b$  as the unknown quantities. By combining these equations, you can get an equation with only ONE UNKNOWN.

$$9. \quad 24 - 0.25I_b - 0.15I_g = 0$$

$$10. \quad 4 + 0.1I_b - 0.2I_g = 0$$

Now multiply Equation 10 by 2.5 to make the  $I_b$  term in each equation have the same value. Then—

$$11. \quad 24 - 0.25I_b - 0.15I_g = 0$$

$$12. \quad 10 + 0.25I_b - 0.5I_g = 0$$

You can cancel the  $I_b$  term by ADDING the two equations (to answer Question *e*)

$$13. \quad 34 - 0.65I_g = 0$$

$$I_g = \frac{34}{0.65} = 52.3 \text{ amperes (Ans.)}$$

You can obtain an equation with  $I_b$  (Question *d*) as the only unknown by substituting the known value of  $I_g$  in Equation 3—

$$14. \quad 4 - (52.3)(0.2) + 0.1I_b = 0$$

$$I_b = 64.6 \text{ amperes (Ans.)}$$

The load current (Question *c*) is equal to the sum of the generator and battery currents—

$$I_L = I_b + I_g = 64.6 + 52.3 = 116.9 \text{ amperes (Ans.)}$$

The generator terminal voltage (Question *a*) will be equal to the battery emf minus the drop across the internal resistance—

$$E_t = 24 - 0.1(64.6) = 17.54 \text{ volts (Ans.)}$$

### SAMPLE PROBLEM NO. 5

A generator, battery, and load circuit are connected as shown in the preceding problem. The generator voltage, armature resistance, battery emf, and internal resistance have the same values as in the preceding problem. But, in this case the load current is to be 150 amperes. Find: (a) the current supplied by the generator, (b) the current supplied by the battery, (c) the generator terminal voltage, (d) the battery terminal voltage.

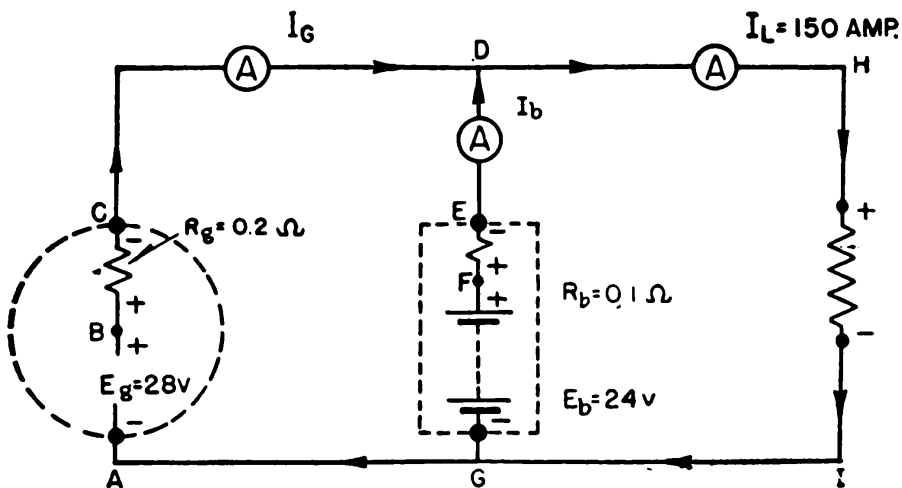


Figure 6.—Schematic diagram, and sample problem No. 5.

You have the schematic diagram for this problem in figure 6. ASSUME that the current flows in the direction indicated by the arrows. By starting at *A* and taking the *IR* drops around the path *A, B, C, D, E, F, G*, you can write Equation 1—

$$1. \quad E_g - I_g R_g + I_b R_b - E_b = 0$$

This equation contains two unknown quantities. You can reduce it to an equation with one unknown quantity by considering the relationship between currents at junction *D*, using Kirchhoff's First Law. Equations 2 and 3 express this relationship.

$$2. \quad I_b + I_g = I_L = 150$$

$$3. \quad I_b = 150 - I_g$$

By substituting this general value of  $I_b$  in Equation 1, you obtain Equation 4. Solve Equation 4 for its one unknown quantity—the generator current—(Question *a*)

$$\begin{aligned} 4. \quad E_g - I_g R_g + I_b R_b - E_b &= 0 \\ 28 - 0.2I_g + 0.1(150 - I_g) - 24 &= 0 \\ 4 - 0.2I_g + 15 - 0.1I_g &= 0 \\ -0.3I_g &= -19 \\ I_g &= 63.33 \text{ amperes (Ans.)} \end{aligned}$$

You can find the battery current (Question *b*) by substituting this value of generator current in equation 3.

$$\begin{aligned} I_b &= 150 - I_g \\ I_b &= 150 - 63.33 \\ I_b &= 86.67 \text{ amperes (Ans.)} \end{aligned}$$

Terminal voltage of generator (Question *c*) =

$$\begin{aligned} E_g - I_g R_g &= 28 - [63.33(0.2)] \\ &= 28 - 12.67 \\ &= 15.33 \text{ volts (Ans.)} \end{aligned}$$

Terminal voltage of battery (Question *d*) =

$$\begin{aligned} E_b - I_b R_b &= 24 - (86.67)(0.1) \\ &= 24 - 8.67 \\ &= 15.33 \text{ volts (Ans.)} \end{aligned}$$

And there you have it!

#### SAMPLE PROBLEM NO. 6

A generator with an induced emf of 28 volts and an armature resistance of 0.2 ohm is connected in parallel with a battery and load circuit as in figure 7. The battery emf is 24 volts and its internal resistance is 0.1 ohm. Find (*a*) the value of the load current

when the battery is FLOATING ON THE LINE, (b) the terminal voltage and current through the generator, and (c) the terminal voltage and current through the generator when the load switch is open.

A BATTERY FLOATS ON A LINE when the CURRENT through it is ZERO. Under this condition, the gen-

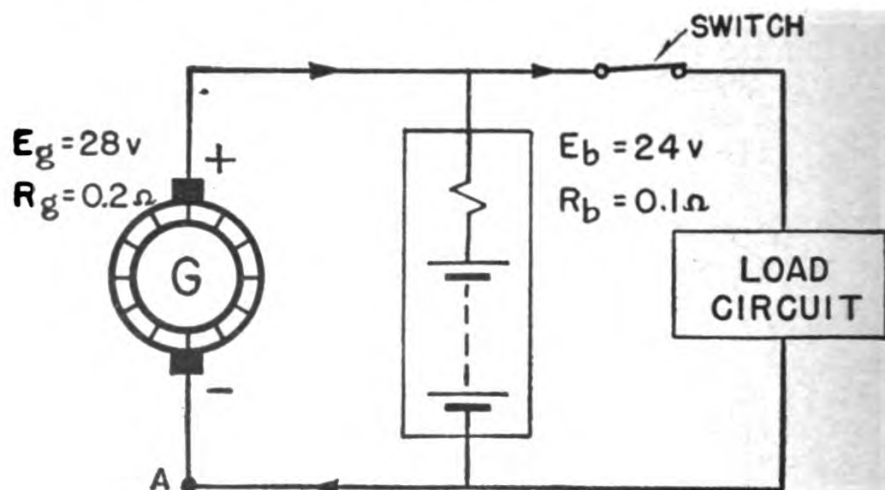


Figure 7.—Schematic diagram,—sample problem No. 6.

erator terminal voltage must be exactly equal to the battery emf. The following equation expresses this fact—

$$E_g - I_g R_g = E_b$$

Since  $I_g = I_L$ , substitute,

$$\text{Then, } I_L R_g = E_g - E_b = 28 - 24 = 4 \text{ volts}$$

$$I_L R_g = 4$$

$$I_L = \frac{4}{R_g} = \frac{4}{0.2} = 20 \text{ amp.} \quad (\text{Ans.})$$

Next, generator terminal voltage =

$$E_g - I_g R_g = 28 - 20(0.2) = 28 - 4 = 24 \text{ volts (Ans.)}$$

If the load switch is opened, there is only one path for current—through the battery. Start at A, and pass around the generator-battery circuit. You obtain—

$$E_g - I_g R_g - I_b R_b - E_b = 0$$

$$\text{Since } I_b = I_g,$$

$$28 - 0.2I_g - 0.1I_g - 24 = 0$$

$$-0.3I_g = -4$$

$$I_g = 13.33 \text{ amperes}$$

Generator terminal voltage =

$$\begin{aligned} E_g - I_g R_g &= 28 - 0.2 (13.33) \\ &= 28 - 2.67 \\ &= 25.33 \text{ volts} \quad (\text{Ans.}) \end{aligned}$$

Battery terminal voltage =

$$\begin{aligned} E_b + I_b R_b &= 24 + .1 (13.33) \\ 24 + 1.33 &= 25.33 \text{ volts} \quad (\text{Ans.}) \end{aligned}$$

Now work out these sample problems to test your ability to apply KIRCHOFF'S LAWS. The answers are given on page 21. But work 'em out BEFORE you look!

#### SAMPLE PROBLEM NO. 7

Two batteries, *A* and *B*, having emf's of 5 and 4 volts, and internal resistance of 1.2 and 1.0 ohms respectively, are connected in parallel, as in figure 8. A resistor  $R_L$ , of 2.5 ohms, is connected between their common terminals. Find: (a) The current through the resistor, (b) The current through each battery, (c) The terminal voltage of the combination.

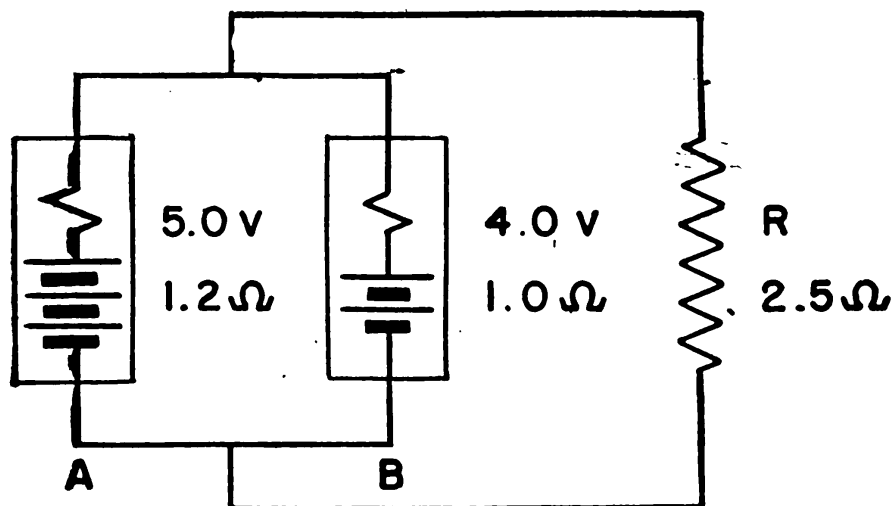


Figure 8.—Schematic diagram, and problem No. 7.



### SAMPLE PROBLEM NO. 8

A storage battery having an emf of 8 volts and an internal resistance of 0.5 ohm is connected in opposition across a 20-volt source with an internal resistance of 0.1 ohm, shown in figure 9. The resistance of all connecting wires is 1 ohm. Find: (a) The current through the battery, (b) The terminal voltage of the battery.

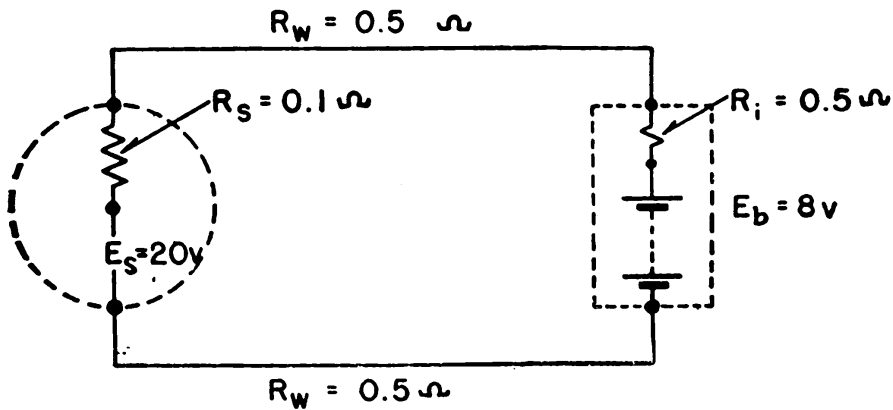


Figure 9.—Schematic diagram, and problem No. 8.

### VOLTAGE DIVIDERS

Electrical devices requiring a definite voltage must often be operated from a source of higher voltage. You can then use a VOLTAGE-DROPPING RESISTOR or a VOLTAGE-DIVIDER.

You see the simplest form of voltage-drop circuit in figure 10. A device that requires 12 volts at 2 amperes is to be operated from a 48-volt source. The voltage-dropping resistor is placed in series with the electrical device. This is a series circuit. And the voltage across each unit will be in proportion to its resistance. If resistor  $R_1$  has the proper value, the voltage across it can be made the difference between 48 volts and 12 volts (or 36 volts). The current through each device in a series circuit is always the

same. Hence, the current through  $R_1$  must also be 2 amperes. By a simple application of Ohm's Law, you find the resistance  $R_1$ .

$$R_1 = \frac{E_1}{I_1} = \frac{36}{2} = 18 \text{ ohms}$$

Occasionally you must operate several low-voltage devices from a single high-voltage source. In this

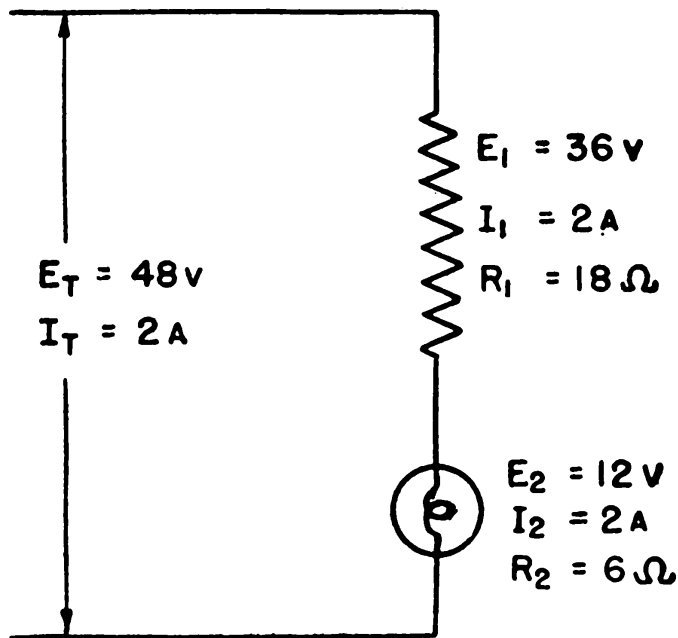


Figure 10.—Voltage-drop circuit.

case, you can insert a SERIES RESISTOR for each separate device. But when the number of devices is large and more than one device operates at the same voltage value, you may advantageously use a VOLTAGE DIVIDER CIRCUIT.

In figure 11, you have the voltage-divider circuit that provides a series of lower voltages from a high voltage source. Here the devices of the circuit are to be operated at two different voltage levels. The three resistance units connected to the source make up the voltage-divider circuit.

You can find the resistance elements that comprise

this voltage-divider circuit only if you know the number of devices, the voltage of each device, and the current for each device, and you must know the voltage-current characteristic of the power supply.

Most power supplies, particularly auxiliary power devices, such as "B" supplies for radio receivers, have a certain amount of internal resistance. So the voltage

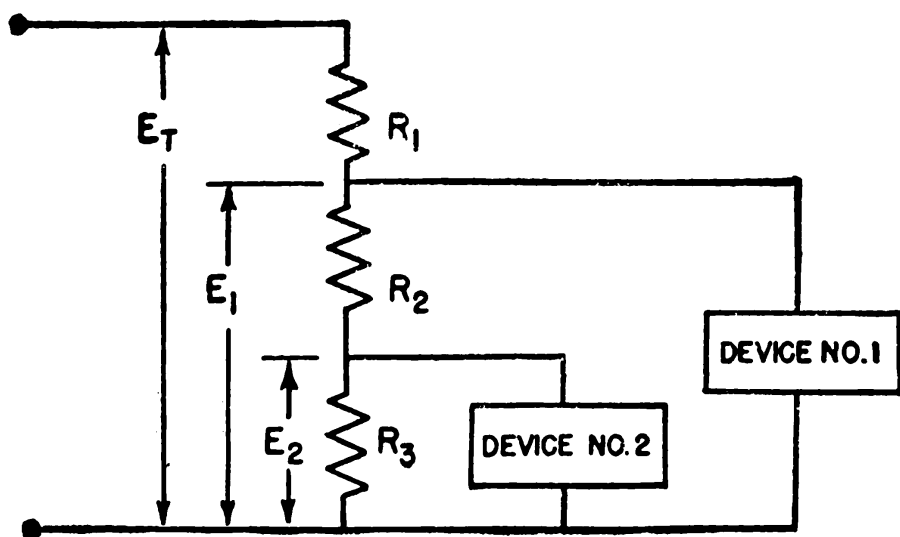


Figure 11.—Voltage-divider circuit.

obtained at the power supply terminals varies with the current output. When the terminal voltage of the power supply remains CONSTANT over a wide range of current output, the power supply is said to have GOOD regulation. If the voltage drops off rapidly as the current drain is increased, the unit is said to have POOR regulation.

If you are to design a voltage-divider for use with a power supply that has poor regulation, you must know the terminal voltage of the power supply at the maximum total value of current required by the load circuits AND the voltage-divider. If you do not have this information, you can easily get it by determining the regulating characteristics of the supply.

You have in figure 12 a simple circuit that helps you obtain these data. Connect a variable resistance

across the terminals of the power supply. By varying this resistance, you determine the terminal voltage over a wide range of load-current values. If you plot these values in a graph, you obtain a characteristic curve similar to that of figure 12B. With the information contained in this graph, you can design a voltage-divider or alter any existing voltage-divider as changes in the load-circuit occur. But—

Before proceeding with the actual design of a voltage-divider, you must get one more value. Look at figure 12C. When TWO voltage levels are required,

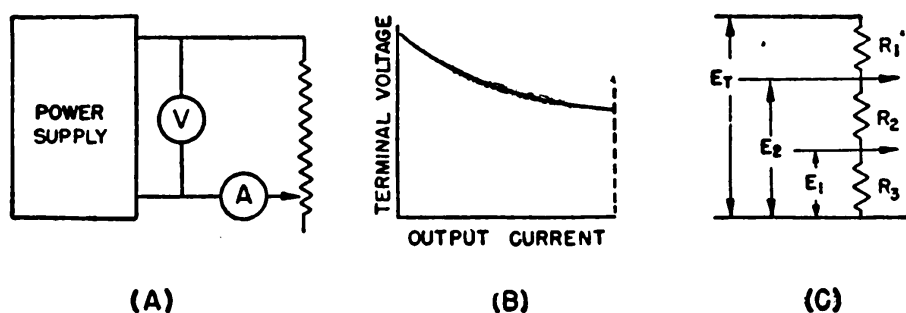


Figure 12.—Voltage-regulation circuit.

you use THREE resistors. Resistor  $R_3$ , referred to as the BLEEDER RESISTOR, stabilizes the voltage at the other taps. When the power supply has excellent regulation and the current drawn from the taps is fairly constant, you may eliminate this resistor. Because power supplies rarely have excellent regulation, this third resistor is usually included.

The current through the bleeder resistance is known as the BLEEDER CURRENT. Any current through this resistor is wasted in heat. The value of current chosen is a compromise between voltage-stability and power loss. The choice will also depend on the characteristics of the individual power supply, and the type of electrical devices operated from the various taps. A representative value for bleeder current would be between 5% and 10% of the full-load current.

## SAMPLE PROBLEM

The power supply is to be used to operate four different circuits, figure 13, each of which requires separate voltage. The devices in Circuit 1 require 6 amperes at 48 volts. Circuit 2 contains devices that require 4 amperes at 26 volts. Circuit 3 requires 8 amperes at 14 volts, and Circuit 4 requires 12 amperes at 6 volts. The power supply has the regulation char-

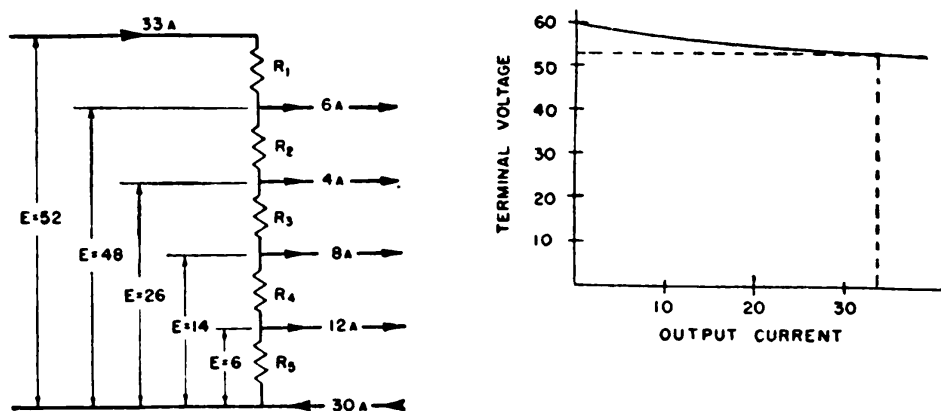


Figure 13.—Regulation characteristic.

acteristic curve you see at the right in figure 13. Calculate the resistance values required for a voltage-divider circuit.

In the figure, you have the general set-up of the divider circuit. There are five separate resistors connected in series across the power supply. The connections between resistors serve as taps for leading off the current to the different circuits. The voltage between each tap and the negative terminal of the supply must correspond to the voltage requirements of the circuit bridged across these points.

**SOLUTION—**

Load Current  $= 6 + 4 + 8 + 12 = 30$  amps.

Bleeder Current  $= 10\%$  of 30 amps.  $= 3$  amps.

Total Current  $= 30 + 3 = 33$  amps.

Figure 13 shows that the power supply has a terminal voltage of 52 volts at 33 amperes.

THEN—

$R_1$  must drop the voltage from 52 volts to 48 volts

Voltage drop across  $R_1 = 52 - 48 = 4$  volts

Current in  $R_1 = 33$  amperes

$$R_1 = \frac{E}{I} = \frac{4}{33} = 0.12 \text{ ohm}$$

$R_2$  must drop the voltage from 48 to 26 volts

Voltage drop across  $R_2 = 48 - 26 = 22$  volts

Current through  $R_2 = 33 - 6 = 27$  amperes

$$R_2 = \frac{E}{I} = \frac{22}{27} = 0.81 \text{ ohm}$$

$R_3$  must drop the voltage from 26 to 14 volts

Voltage drop across  $R_3 = 26 - 14 = 12$  volts

Current through  $R_3 = 27 - 4 = 23$  amperes

$$R_3 = \frac{E}{I} = \frac{12}{23} = 0.52 \text{ ohm}$$

$R_4$  must drop the voltage from 14 to 6 volts

Voltage drop across  $R_4 = 14 - 6 = 8$  volts

Current through  $R_4 = 23 - 8 = 15$  amperes

$$R_4 = \frac{E}{I} = \frac{8}{15} = 0.53 \text{ ohm}$$

$R_5$ , the bleeder resistor, must drop the voltage from 6 to 0 volts

Voltage drop across  $R_5 = 6 - 0 = 6$  volts

Current through  $R_5 = 15 - 12 = 3$  amperes  
(bleeder current)

$$R_5 = \frac{E}{I} = \frac{6}{3} = 2 \text{ ohms}$$

## ANOTHER SAMPLE PROBLEM

Four lamps are to be operated from a 100-volt source which has excellent regulation. The voltage and current requirements for each lamp are—

- Lamp #1 — 100 volts; 3 amperes
- Lamp #2 — 80 volts; 4 amperes
- Lamp #3 — 48 volts; 3 amperes
- Lamp #4 — 12 volts; 2 amperes

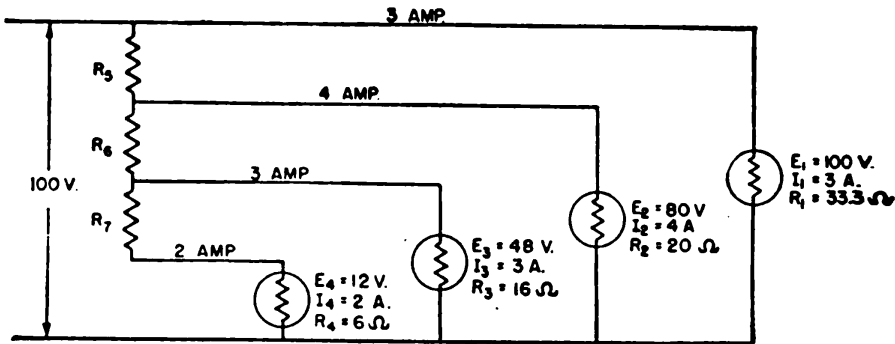


Figure 14.—Voltage-divider schematic diagram, sample problem.

Design a voltage-divider for this circuit. See figure 14. Assume that the source has a terminal voltage of 100 volts at the required current drain.

The power supply regulation is excellent, so the devices are operated at constant current. You can OMIT THE BLEEDER RESISTOR.

$R_5$  drops the voltage from 100 to 80 volts

Voltage-drop across  $R_5 = 100 - 80 = 20$  volts

Current through  $R_5 = I_2 + I_3 + I_4 = 9$  amperes

$$R_5 = \frac{E}{I} = \frac{20}{9} = 2.22 \text{ ohms}$$

$R_6$  drops the voltage from 80 to 48 volts

Voltage drop across  $R_6 = 80 - 48 = 32$  volts

Current through  $R_6 = I_3 + I_4 = 5$  amperes

$$R_6 = \frac{E}{I} = \frac{32}{5} = 6.4 \text{ ohms}$$

$R_7$  drops the voltage from 48 to 12 volts  
Voltage drop across  $R_7 = 48 - 12 = 36$  volts  
Current through  $R_7 = 2$  amperes

$$R_7 = \frac{E}{I} = \frac{36}{2} = 18 \text{ ohms}$$

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### ANSWERS TO PROBLEMS

On pages 13 and 14

#### Problem No. 7

- (a) 1.463 amps.
- (b) 1.119 amps.; 0.344 amp.
- (c) 3.657 volts

#### Problem No. 8

- (a) 7.5 amps.
- (b) 11.75 volts







## CHAPTER 2

# MEASUREMENT INSTRUMENTS

## D-C METERS

There'll be times when you'll want to check up on some circuits to see what's going on, how much current is flowing, what voltage you have, and so on. You may want to repair a circuit that's out of commission, or you may even be building a new circuit. On these jobs you can make good use of instruments to measure voltage, current, and resistance. And if you know how the various instruments work, you'll know why they give you the information you need. You'll also know how to check on their operation.

First you'll become acquainted with meters for measuring d.c.

## GALVANOMETER

One of the simplest and most commonly-used instruments is the MOVING-COIL GALVANOMETER. Look at figure 15. The galvanometer has a core made of soft iron. A coil of very fine wire is wound on an aluminum form around the core. The turns of wire make up the armature coil. The core is rigidly fas-

tened, but the coil form is mounted on a shaft seated in jewel bearings so as to be free to turn about the core. Rotation of the coil is controlled by a spring on each end of the shaft. These springs also act as current leads to the movable coil. The core and coil are placed between the poles of a U-shaped permanent

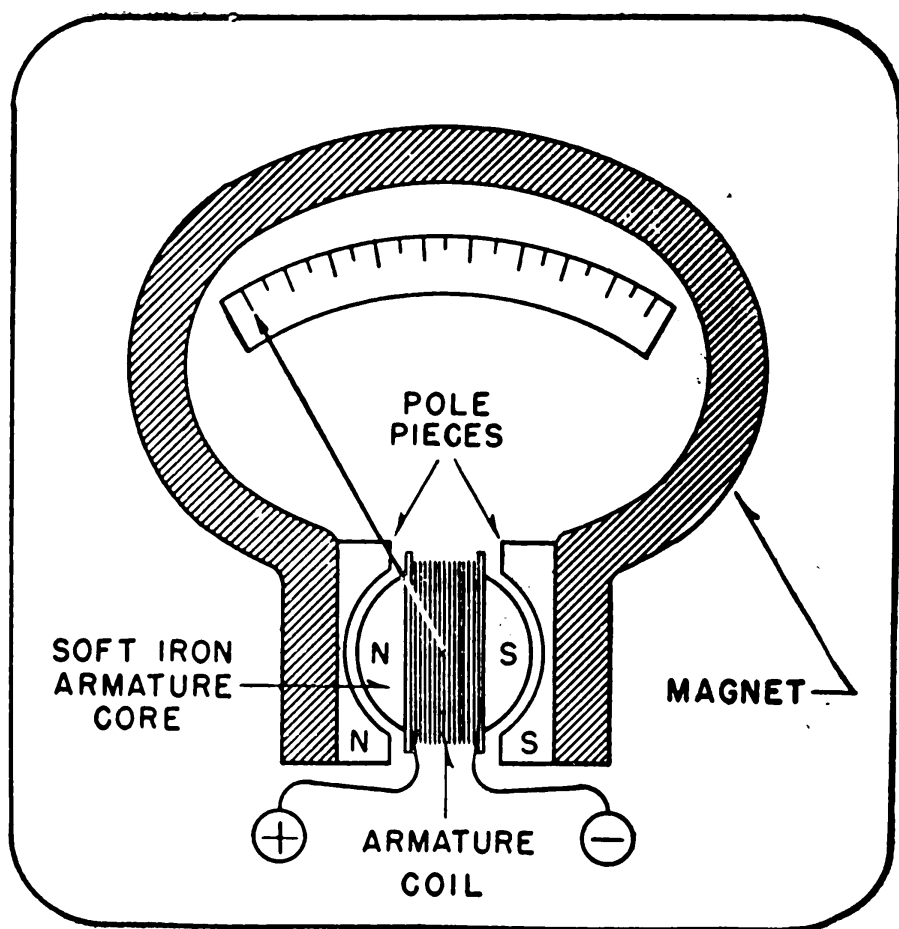


Figure 15.—Moving-coil galvanometer.

magnet. One end of a pointer is fastened to the armature shaft. As the shaft rotates, the other end of the pointer moves over a calibrated dial.

Current through the armature coil sets up a magnetic field. This coil field reacts with the magnetic flux of the permanent U-shaped magnet to rotate the coil with respect to the magnet. On this principle, current through the coil makes the coil turn a propor-

tional amount. You can measure the travel of the pointer attached to the coil to determine the amount of current flowing through the meter.

The galvanometer is designed so that the maximum rotation of the armature is completed in less than a half-turn in a clockwise direction. The whole working assembly is enclosed in a glass-faced case that protects it from dust and air currents.

When you connect the galvanometer in the circuit, make sure that the leads carrying the current are attached to the correct binding posts. The posts are marked POSITIVE and NEGATIVE. The positive lead must be connected to the positive binding post, and the negative lead must be connected to the negative binding post. If this connection is reversed, the armature will start to rotate in the opposite direction and the meter may be damaged.

The simple galvanometer just described is designed to measure very small currents, usually no more than a few milliamperes. Often you must measure greater currents. Then you connect a metal bar, or SHUNT, across the galvanometer terminals.

Shunts have various carefully-calibrated resistances. Generally, the shunt resistance is only a fraction of the galvanometer resistance. The current divides when it reaches the shunt. Part of the current flows through the galvanometer, and part through the shunt. Because current takes the path of least resistance, the greater portion of the current flows through the shunt.

The shunts must be carefully made and marked, or calibrated, to match the galvanometer. Unless you have a precise ratio of resistance between meter and shunt, you won't know accurately what the galvanometer readings really mean.

Suppose that 5 milliamperes of current is necessary to cause a full-scale deflection of the pointer. Also suppose that the resistance of the galvanometer arma-

ture itself is 99 ohms, and that you install a shunt which has a resistance value of 1 ohm. Because the resistance of the galvanometer is 99 times that of the shunt,  $\frac{99}{100}$ ths of the current will flow through the shunt. The remaining  $\frac{1}{100}$ th will flow through the galvanometer.

For example, your 5-milliampere galvanometer reads 4 milliamperes, indicating that 4 milliamperes must be flowing through the galvanometer. The resistance of the galvanometer is 99 times as great as the resistance of the shunt. Hence 99 times as much current must be flowing through the shunt itself. By simple multiplication of  $99 \times 4$ , you get a value of 396 milliamperes for the current flowing through the shunt. Add to this the 4 milliamperes flowing through the meter. A total of 400 milliamperes of current flows in the entire circuit.

### AMMETER

As you already know, an AMMETER measures CURRENT, and must be connected to the circuit IN SERIES. When you insert the shunt, your galvanometer actually becomes an ammeter.

You can use the same galvanometer with shunts of various resistances. If you know the resistance of the galvanometer, you can calculate the resistance of the shunt necessary to extend the range of the meter to a desired point. Here's a formula you can use.—

$$R = \frac{R_m}{(N-1)}$$

$R$  is the resistance desired for the shunt.  $R_m$  is the resistance of the meter.  $N$  is the multiplication factor necessary to raise the range of the meter to the desired point.

FOR INSTANCE—Suppose the resistance,  $R_m$ , of the meter is 3 ohms, and the full-scale deflection repre-

reads 5 milliamperes. What do you do to find the value of the shunt necessary to extend the range of the meter to 100 milliamperes? First, divide 100 milliamperes by 5 milliamperes to get the multiplication factor,  $N$ , which turns out to be 20.

So—

$$R = \frac{R_m}{(N-1)} = \frac{3}{(20-1)} = \frac{3}{19} = 0.158 \text{ ohm}$$

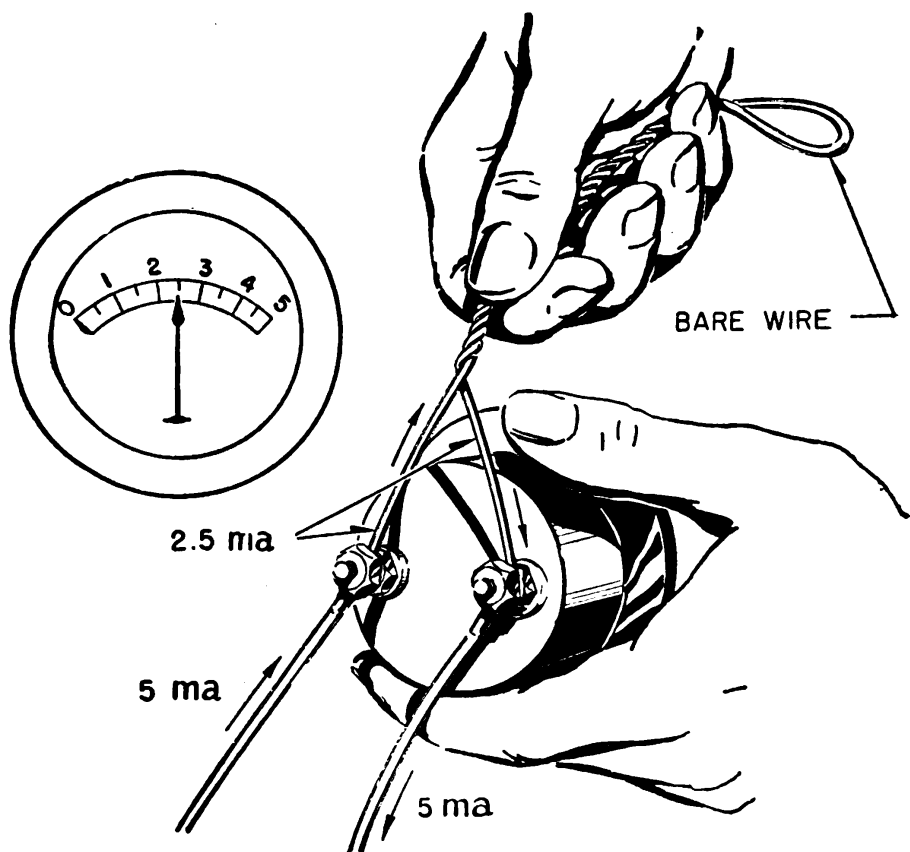


Figure 16.—Range-extension with twisted-wire shunt.

Most meters are supplied with built-in or internal shunts. How can you extend the range of such a meter? To each terminal, you connect the ends of a wire. Then you twist the loop of wire together to form a shunt passage for the current across the meter, as in figure 16. To adjust the shunt resistance to the correct value, you ADD some twists or you partly UN-

TWIST the wire, depending on whether you need MORE or LESS resistance.

Suppose the original full-scale deflection of the meter represents 5 milliamperes, and suppose you must extend the range to 10 milliamperes. WHEN THE CURRENT STEADY AT 5 MILLIAMPERES, you twist the wire together until the needle drops back to mid-scale deflection, or to read 2.5 milliamperes. Now the full-scale reading of the meter will represent 10 milliamperes.

You measure the potential difference existing between two points in a circuit by means of a voltmeter. See figure 17. As you know, voltage is a force which

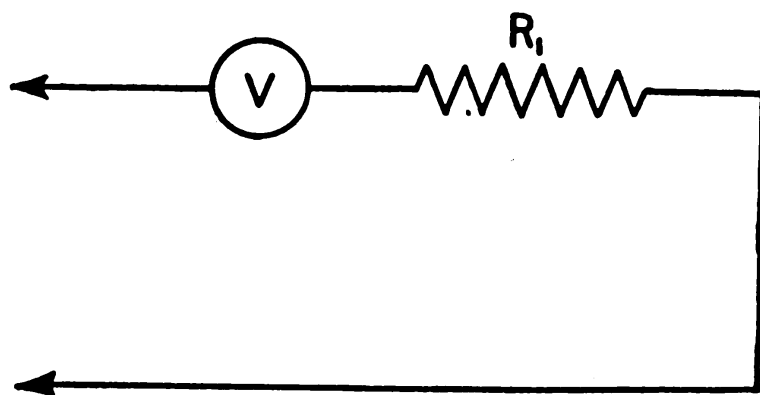


Figure 17.—Voltmeter circuit.

causes current to flow in a circuit. The amount of current flowing in a circuit is dependent on, and proportional to, the amount of voltage.

Suppose a voltmeter with an internal resistance of 1,000 ohms gives a full-scale deflection when 1 volt is applied. To place this instrument across a circuit where the voltage is greater than 1 volt, you must ADD SERIES RESISTANCE. This limits to a safe value the amount of current flowing through the instrument. The resistor you add is called a MULTIPLIER, because it multiplies the range of the meter.

Again, suppose that the resistance of the moving

oil plus the original series resistance is 1,000 ohms. If you increase the resistance of the meter to 2,000 ohms by adding 1,000 ohms in series, the pointer falls from FULL-scale reading to HALF-scale reading. Where 1 volt was formerly indicated by a full-scale reading, it is now indicated by a half-scale reading. You have, therefore, extended the range of the voltmeter from 1 volt to 2 volts.

You can use a simple formula to find the resistance necessary to extend the range of a voltmeter to a desired point—

$$R_x = \frac{R_m (V_2 - V_1)}{V_1}$$

$R_x$  is the desired resistance.  $R_m$  is the meter resistance.  $V_2$  is voltage to be measured, and  $V_1$  is the voltage of the meter.

Here's a problem. The resistance  $R_m$  of your 3-volt meter is 1,000 ohms. You wish to increase the range of your meter to 25 volts ( $N=25$ ). Then—

$$R_x = \frac{R_m (N - 3)}{3}$$

$$R_x = \frac{1,000 (25 - 3)}{3} = 7,333 \text{ ohms}$$

So you need a 7,333-ohm resistor connected in series with the meter to increase the range of your voltmeter to 25 volts.

REMEMBER that in extending the range of a voltmeter, you must increase the amount of multiplier resistance. Because the multiplier resistance remains constant for a given voltage range, the indication on the voltmeter increases with the voltage.

In measuring resistance, you use the VOLTMETER-AMMETER method. The discussions in the following paragraphs will help you make the best connections using these meters.



To measure LOW values of resistance, connect the voltmeter DIRECTLY ACROSS THE RESISTANCE. If the load resistance is HIGH, connect the voltmeter ACROSS BOTH AMMETER AND LOAD. Another point—you should always use a voltmeter that has a very HIGH resistance. And here's WHY—

In figure 18A, you have the circuit that you would use to find resistance by the ammeter-voltmeter

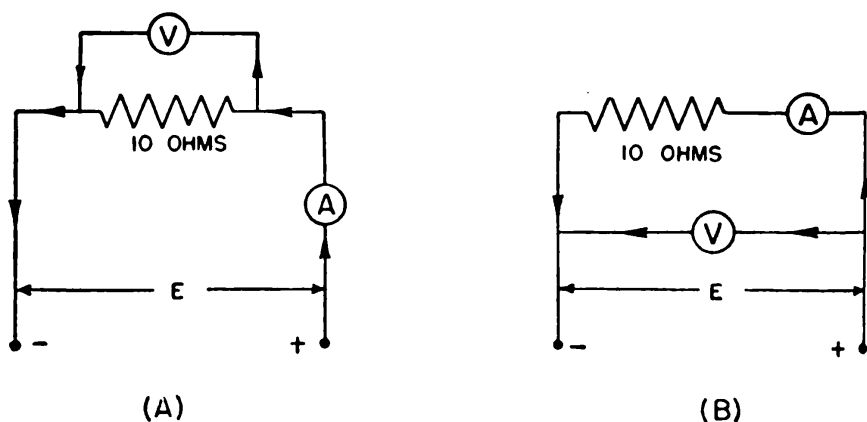


Figure 18.—Resistance measurement by ammeter-voltmeter method.

method. Here the voltmeter should measure the voltage actually applied to the resistor. The ammeter should measure the current through it. You can easily see that the voltmeter does measure voltage through the resistor. But the ammeter is not measuring the current through the resistor alone. It measures the current through BOTH the resistor and the voltmeter. If the current through the voltmeter is large, you introduce a considerable error in substituting these values in the formula for Ohm's Law.

Suppose you want to measure a resistance which you already know is 10 ohms. For convenience, you apply a voltage to the circuit so that the voltmeter  $V$  reads 10 volts. Then the current  $I$  through the 10-ohm resistor would be—

$$I_R = \frac{E_R}{R_R} = \frac{10}{10} = 1 \text{ ampere}$$

But your voltmeter has an internal resistance of 100 ohms. So, the current through the voltmeter is—

$$I_v = \frac{E_v}{R_v} = \frac{10}{100} = 0.1 \text{ ampere}$$

Now if you put these readings in the formula for total circuit resistance, you get—

$$R = \frac{E}{I} = \frac{E}{I_R + I_v} = \frac{10}{1 + 0.1} = \frac{10}{1.1} = 9.09 \text{ ohms}$$

and your ammeter reading would be 1.1 amperes.

But you already know that  $R = 10$  ohms, so you have an error of  $10 - 9.09$  or  $0.91$  ohm, all because you have connected your ammeter in figure 18A so that it measures current through the resistor AND the voltmeter. You are using a false reading for current through the resistor alone.

Now suppose the resistance of the voltmeter happened to be 10,000 ohms, instead of 100 ohms. Then—

$$I_R \text{ would still be } I_R = \frac{E_R}{R_R} = \frac{10}{10} = 1 \text{ ampere.}$$

But—

$$I_v \text{ now is } I_v = \frac{E_v}{R_v} = \frac{10}{10,000} = 0.001 \text{ ampere,}$$

and—

$$I_v + I_R = 1 + 0.001 = 1.001 \text{ amps.}$$

Then, in this case the calculated resistance of  $R$  is—

$$R = \frac{E}{I} = \frac{10}{0.001} = 9.99 \text{ ohms}$$

But you know that  $R$  actually equals 10 ohms, so your calculated error is  $10 - 9.99$  or  $0.01$  ohm. You can see now that in order to get an accurate reading for the circuit connection of figure 18A, you ought to use a voltmeter with a HIGH internal resistance as compared to the resistance to be tested.

If you know the resistance of a voltmeter, you can figure the voltmeter current for any voltage reading. Then you subtract this current from the ammeter reading to determine the ACTUAL CURRENT through the resistor. If you are to get the correct resistance value of the resistor itself, you must substitute this actual value of resistor current in your formula,

$$R = \frac{E}{I}.$$

In figure 18B, you have a slight variation from the original circuit diagram. The ammeter is now connected between the voltmeter and the resistor. Now the current taken by the voltmeter is of no importance. With this particular arrangement, the ammeter reads the TRUE current through the resistor. But the voltmeter is not measuring the voltage applied to the resistor. The voltmeter measures the voltage across the series combination of ammeter AND resistor.

Suppose the ammeter has a resistance of 1 ohm, and the resistor to be measured has a resistance of 10 ohms. If the applied voltage causes a current of 1 ampere to flow, the ACTUAL voltage applied to the resistor is—

$$E = I_R R_R = 1 \times 10 = 10 \text{ volts.}$$

The voltmeter will not indicate 10 volts, because the drop across the ammeter is included. The drop is  $E = IR = 1 \times 1 = 1$  volt. The total voltage reading is 11 volts. If you put these meter readings in the

formula,  $R = \frac{E}{I} = \frac{11}{1} = 11$ , you get a value of 11

ohms for the resistance. The error is  $11 - 10$  or 1 ohm.

If the resistance of the ammeter is only 0.001 ohm, the resistance of ammeter AND resistor becomes  $10 + 0.001 = 10.001$ , and the voltmeter reading would be

come  $E = IR = 1 \times 10.001 = 10.001$  volts. The resistance of the resistor is calculated as

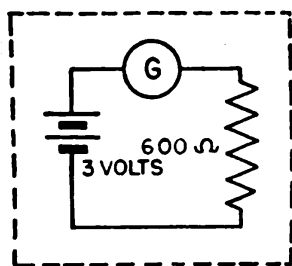
$$R = \frac{E}{I} = \frac{10.001}{1} = 10.001 \text{ ohms.}$$

Here the error

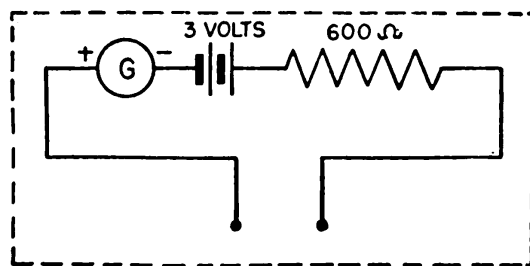
would be only  $10.001 - 10$  or  $0.001$  ohm. So the error is large only if the ammeter resistance is about equal to the load resistance. And the lower the resistance of the ammeter, the lower the error.

### OHMMETER

You can convert an ammeter into an OHMMETER. In figure 19A, you have a 3-volt battery connected to a milliammeter with a full-scale reading of 5 milliam-



(A)



(B)

Figure 19.—Ohmmeter circuit.

peres. The current-limiting resistor  $R$  has a value such that exactly five milliamperes flow in the circuit. This resistance is found by a simple application of Ohm's Law. Since  $E = 3$  volts, and  $I = .005$  amperes, the proper limiting resistance is—

$$R = \frac{E}{I} = \frac{3}{.005} = 600 \text{ ohms.}$$

In figure 19B, the circuit has been equipped with two binding posts. With no connection across the

posts, the current will be zero. If you close the circuit at these posts through practically zero resistance, the meter will return to its full-scale reading of 5 milliamperes. If you connect a second 600-ohm resistor between the binding terminals, the total resistance is now 1,200 ohms. The meter will drop to one-half its former reading, or to read 2.5 milliamperes, since

$$I = \frac{E}{R} = \frac{3}{1,200} = 0.0025a = 2.5 \text{ ma.}$$

If the battery voltage and the limiting resistor ( $R$ ) remain constant, the pointer will always move to 2.5 milliamperes whenever you put 600 ohms across the posts. You can now mark this point on the scale of the meter "600 ohms." You have converted the milliammeter into a ohmmeter, capable of reading one value of resistance—600 ohms.

Now put a 2,400-ohm resistor across the binding posts. This plus the original 600 ohms resistance of the meter equals 3,000 ohms total. The pointer will drop to 1 milliampere on the scale, since

$$I = \frac{E}{R} = \frac{3}{3,000} = 0.001 \text{ ampere, or 1 milliampere.}$$

Again if the battery voltage and the limiting resistor remain constant, the meter will always read 1 milliampere when you put a resistance of 2,400 ohms across the posts. So, you can mark "2,400 ohms" alongside the 1-milliampere point on the meter scale. The meter instrument is now capable of measuring 600 ohms and 2,400 ohms.

In a similar manner, by placing other known resistances across the binding posts, you can calibrate the instrument to measure resistance values over the entire range of the meter scale.

## MEASURE RESISTANCE WITH WHEATSTONE BRIDGE

A WHEATSTONE BRIDGE is an instrument used for making accurate resistance measurements. Figure 20 shows the schematic diagram of a typical Wheatstone bridge. It consists essentially of THREE RESISTORS, A SENSITIVE GALVANOMETER, AND A POWER SUPPLY. Two resistors— $R_1$  and  $R_2$  are fixed resistors of known

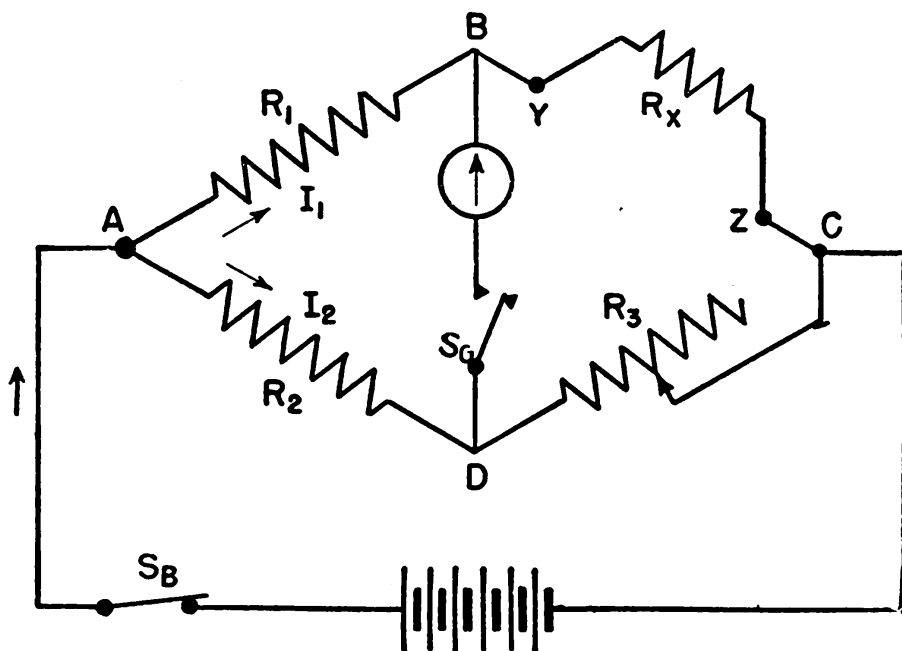


Figure 20.—Schematic diagram, Wheatstone bridge.

values, the third— $R_3$ —is a variable resistor with the necessary calibration arrangement to read the resistance value at any setting. You connect the UNKNOWN resistor— $R_x$ —across the binding posts at Y and Z.

Connect the battery at points A and C. When you close switch  $S_B$ , current flows in the direction of the arrows. You get a voltage drop across all four resistors in the circuit. Ordinarily,  $R_1$  is equal to  $R_2$ . Next, adjust variable resistance  $R_3$  so that the galvanometer registers ZERO when the switch  $S_G$  is closed. At this adjustment,  $R_3$  is equal to  $R_x$  in resistance. By reading the resistance of  $R_3$ , you know the resistance of  $R_x$ .

And here's why and how! Point  $B$  will be at the same electrical potential as point  $D$  if the variable resistance  $R_3$  is equal to  $R_x$ . Under this condition NO current flows through the galvanometer when the galvanometer switch is depressed. If  $R_x$  is not equal to  $R_3$ , then  $B$  and  $D$  are not at the same potential, and current WILL flow through the galvanometer when the switch is closed. But you will adjust  $R_3$  until no current flow is obtained through the meter. Then  $R_3 = R_x$ .

But  $R_1$  and  $R_2$  need not always be equal in resistance.

To get an accurate reading, you should select  $R_1$  approximately equal to what you think  $R_x$  will be. In the most accurate types of Wheatstone bridge, the resistance of  $R_1$  is known, but can be varied in steps. The following formulas show you how to find the unknown resistance of  $R_x$  for any values of  $R_1$ ,  $R_2$ ,  $R_3$ .

$$\begin{aligned} \text{The voltage drop across } AB &= I_1 R_1 \\ AD &= I_2 R_2 \\ BC &= I_1 R_x \\ DC &= I_2 R_3 \end{aligned}$$

$$\begin{aligned} \text{Also} \quad I_1 R_1 &= I_2 R_2 \\ I_1 R_x &= I_2 R_3 \end{aligned}$$

If equals are divided by equals, the results are equal.

Therefore—

$$\begin{aligned} \frac{I_1 R_1}{I_1 R_x} &= \frac{I_2 R_2}{I_2 R_3} \\ \frac{R_1}{R_x} &= \frac{R_2}{R_3} \\ R_x &= \frac{R_1 R_3}{R_2} \end{aligned}$$

When using the Wheatstone bridge, you must be sure that ALL CONTACT POINTS ARE CLEAN so that you won't be putting additional resistance into the circuit. Dirty points will give you false readings.

### WHAT'S A MEGGER?

When you run into more than 10 megohms resistance, the ohmmeter is not a satisfactory meter, because the voltage used in the ohmmeter is very low. A MEGGER overcomes this disadvantage.

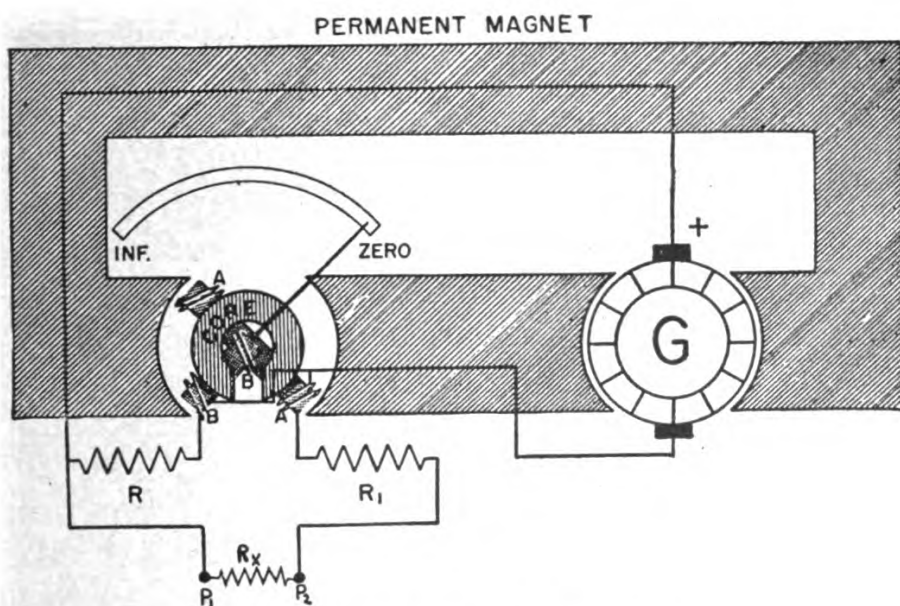


Figure 21.—Working parts of megger.

The megger is a first cousin to the ohmmeter. The megger scale reads measured values of resistance directly. The megger has two main elements, a magneto d-c generator to supply current for making the measurement, and an ohmmeter which measures the value of the resistance you are testing. You turn the armature of the generator by a hand-crank, generator speed being stepped-up by gears. The normal output voltage of the generator is about 500 volts. A schematic diagram of the megger is shown in figure 21.

The indicating element has two coils, which are



mounted on the same shaft, but are set at right angles to each other. You will see that coil *A* is of the same type used in most d-c voltmeters. Coil *B* is smaller and is mounted so that at some positions it encircles a part of the core, which is C-shaped. You feed current to both coils by means of flexible connections that do not hinder the rotation of the element.

Coil *A* is the current coil. Hook one terminal of this coil to the negative brush of the generator and put this coil in series with resistance  $R_1$  to the external terminal  $P_2$ . Lead the other external terminal  $P_1$  to the positive brush of the generator. When you connect an unknown resistance  $R_x$  between the external terminals, current flows from the generator through coil *A*, resistance  $R_1$ , and the unknown external resistance  $R_x$ . Resistance  $R_1$  has enough resistance so that even if the line terminals are short-circuited, the current coil will not be damaged.

Coil *B* is the potential coil. You connect this coil across the armature of the generator through a suitable resistance  $R$ . If the line terminals are left open-circuited or if the external resistance  $R_x$  is of enormous value, no current will flow in coil *A*, and coil *B* alone will move the pointer. Coil *B* will take a position opposite the gap in the C-shaped core and the pointer will indicate INF (infinity). If, however, you put a resistance  $R_x$  between the line terminals, current will flow in coil *A*. The corresponding torque developed will move the indicator away from the INF position into a field of gradually increasing strength until equilibrium is established between the field torques of coils *A* and *B*. You can calibrate the scale in terms of resistance. Since changes of generator voltage affect both coils in the same proportion, variations in the speed of the hand-cranked generator will not affect the readings of the megger.

The 500-VOLT PORTABLE MEGGER is one you use most widely in aircraft work. It has many uses, and you

will learn by experience when and where to use this instrument. Here are some of its uses—

To test insulation resistance of generator, and of dynamotor field coils and connection blocks.

To test for high-resistance grounds, or leakage on antenna, transmitter, and receiver insulators.

To test for high-resistance grounds on radio direction-finder loops.

To test capacitors whose peak voltages are not below the output voltage of the megger.

To test for high-resistance grounds on ignition harness. This is not a very satisfactory method of testing ignition harness, since the voltage on the megger is not high enough for a real test. However, it can be used if you do not have an ignition harness tester, which supplies a much higher voltage.

### A-C METERS

A-C meters are similar in one respect to d-c meters. They are nearly all current-measuring devices. However, the reversals of the a.c. prevent you from using the moving coil-permanent magnet principle. Therefore, you will have to use some method by which force in only one direction is obtained, in spite of the reversal in current. You can do this with five main types of a-c meters. These are the DYNAMOMETER, the HOT-WIRE, the IRON-VANE, the THERMOCOUPLE, and the RECTIFIER-TYPE meters.

In the DYNAMOMETER, you have fixed field-coils and a movable coil to which a pointer is attached. A light spring is attached to this moving-coil to retard its movement.

Here's how the dynamometer works. Look at its action on the first half of the a-c cycle. You've wound your fixed and movable coils so that the magnetic fields have the polarities shown in figure 22. The attraction of the magnetic forces tends to turn the

movable coil in the direction indicated, since its field tries to line up with the fields of the fixed coils. This moves the pointer up the scale to the right. The distance it moves is determined by the coil spring attached to the pointer shaft. When the tension on the spring becomes equal to the pull of the magnetic fields, the pointer will come to rest.

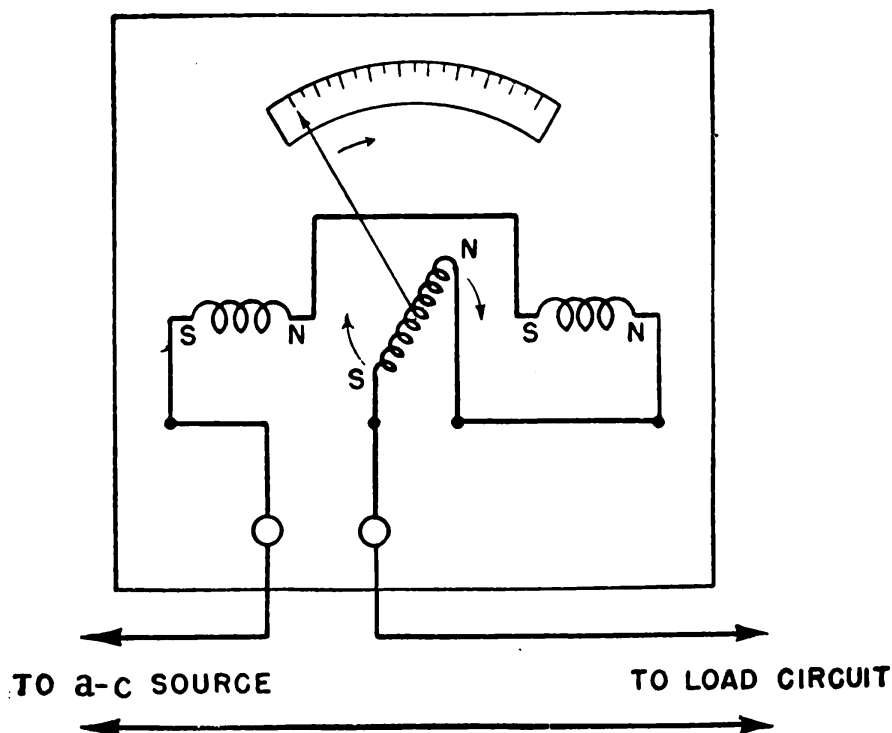


Figure 22.—Dynamometer as an ammeter.

This goes for only one-half cycle. However, you can see that when the current reverses, the polarity of all coils will reverse. When this occurs, the same amount of force is still exerted to turn the movable coil. The direction of rotation is the same as before—to the right or clockwise. So, your meter will always read in a positive direction. The readings are approximately proportional to the square of the current.

Use the dynamometer as a low-current meter or as a laboratory ammeter for small currents. The leads to carry heavy current will be too heavy to make it practical to use the meter for high-current readings.

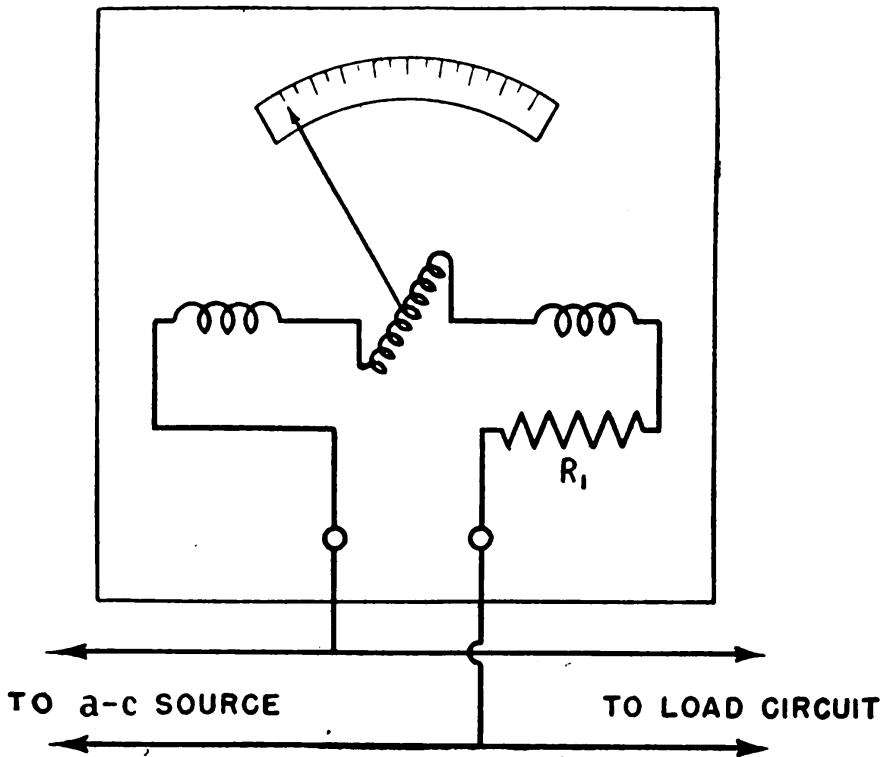


Figure 23.—Dynamometer as voltmeter.

You can use the dynamometer as a voltmeter by connecting a current-limiting resistor  $R_1$  in series with the internal circuit, as in figure 23. The principle is the same for a-c instruments as for d-c instruments.

### HOT-WIRE AMMETER

You'll use the HOT-WIRE AMMETER to measure SMALL ALTERNATING CURRENTS OF RADIO-FREQUENCY. This alternating current travels through a fine wire stretched horizontally between points  $A$  and  $B$  in figure 24. Another wire is attached to point  $C$  on the horizontal wire and is fastened at point  $D$ . A fine thread attached to point  $E$  of this second wire is also attached to the indicator at point  $F$  and tied to a small spring at point  $G$ . As the current passes over the wire  $AB$ , the resistance encountered causes the current to heat and expand the wire. This slight expansion

lengthens the wire. The spring *G* deflects the pointer. The heating effect is proportional to the square of the current through the wire. Hence the calibrated spaces on the scale of a hot-wire ammeter are not equally spaced, but increase as the square increases.

Figure 24B shows relative positions of the wires and pointer when the meter is in operation.

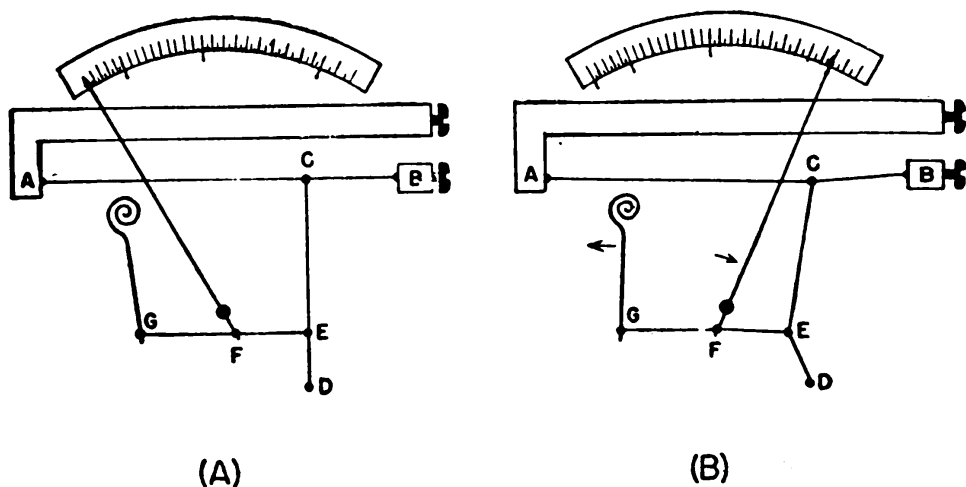


Figure 24.—Hot-wire ammeter.

### IRON-VANE METER

You can also measure a.c. with the IRON-VANE METER. Look at figure 25. This meter has two soft-iron magnetized pieces or vanes mounted inside a coil. One of these vanes is fixed, while the other is free to move. You attach a shaft and pointer to the moving vane. As the current flows through the coil of wire, the two vanes become magnetized.

Since they are magnetized in the same way—with like poles at the same ends—these vanes try to REPEL each other. The free vane moves away from the fixed vane. This turns the shaft and moves the indicator across the calibrated dial. Even though the direction of the current changes on each half-cycle, the two vanes are always magnetized alike, and so continue to

repel each other. Reversals in current have no effect on the indication of the pointer. Since the amount of magnetism developed in the two vanes is directly dependent on the amount of current passing through the

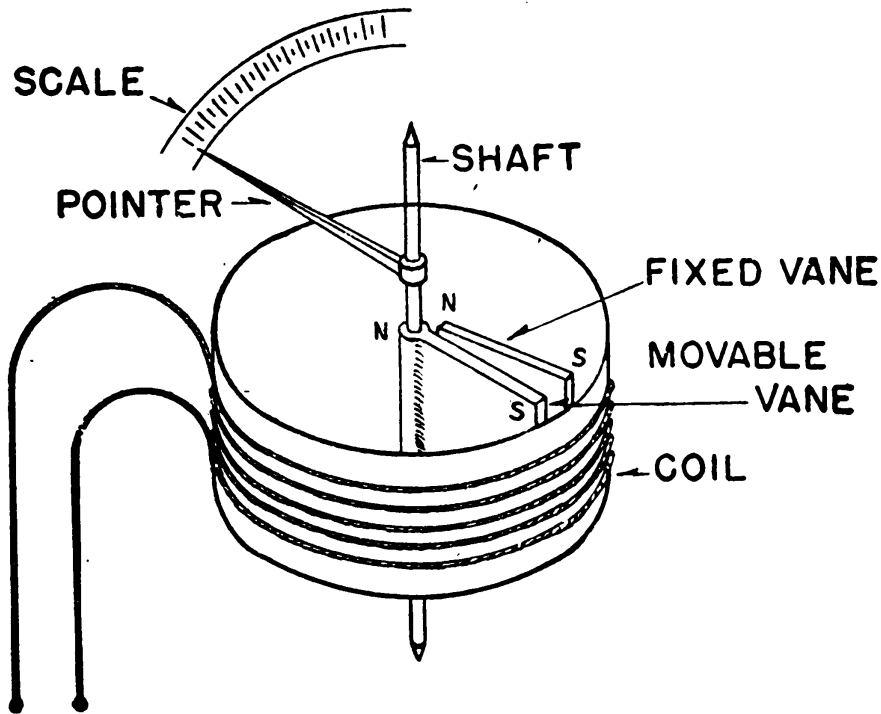


Figure 25.—Iron-vane meter.

coil, the value of the current is indicated by the pointer moving across the uniformly calibrated dial.

### HERE'S THE THERMOCOUPLE METER

Another instrument that you can use in measuring a.c., or radio frequency, is the THERMOCOUPLE METER, figure 26. Here's how it works. When two dissimilar metals are connected at one end, and heat is applied to the CONNECTED ends, a direct-current electromotive force, or d-c voltage, is developed across the OPEN ends of the two dissimilar metals.

This voltage is directly proportional to the temperature of the wires in the heated junction. The generation of d-c voltage by heating the junction of

these two dissimilar metals is called THERMO-ELECTRIC ACTION. This device is called a THERMOCOUPLE.

Any two dissimilar metals will produce a voltage across the open ends, when you heat their junction. But two wires, one an alloy of bismuth and the other an alloy of antimony, will produce the greatest pos-

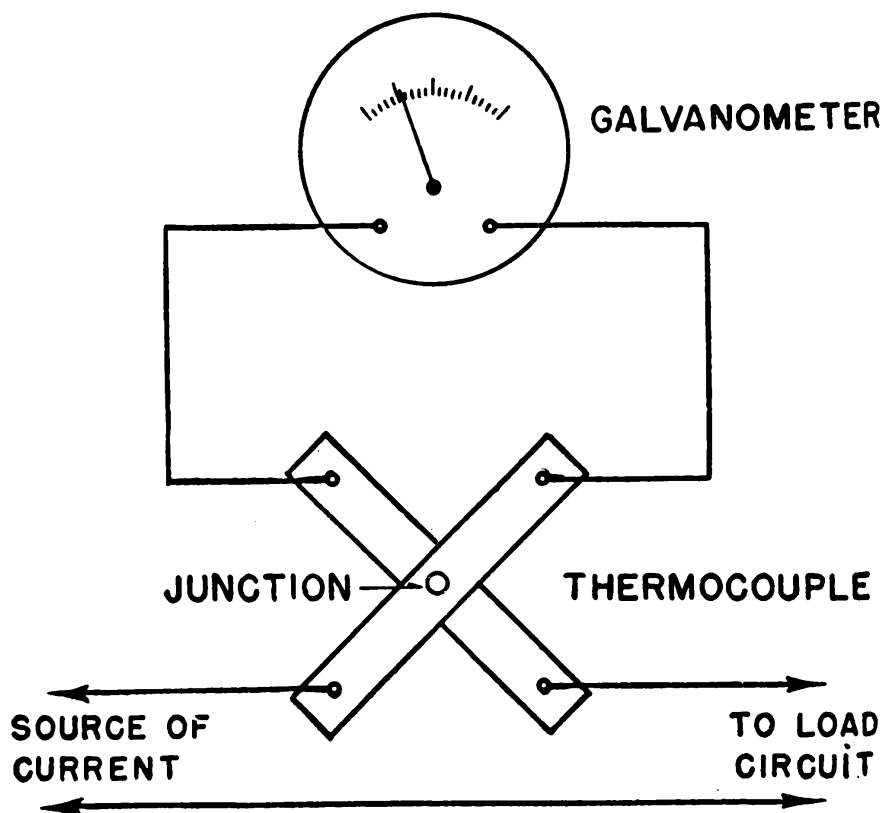


Figure 26.—Thermocouple meter.

sible voltage per degree of temperature difference. An electric current passing through a wire or conductor will produce heat in that wire in proportion to the square of the current. Therefore, if you pass a current through the junction of a thermocouple, heat will be generated in the wires, and a voltage will be produced at the open ends.

If you connect a calibrated galvanometer to the free ends of the thermocouple wires, you can measure this generated voltage. The direction of the current in the

thermocouple has no effect on the heating of the wire. Therefore, you can use the thermocouple to measure either d.c. or a.c.

Frequently, you'll have to measure a.c. without stealing any more power from the current than is absolutely necessary. You can't use the low-power d-c

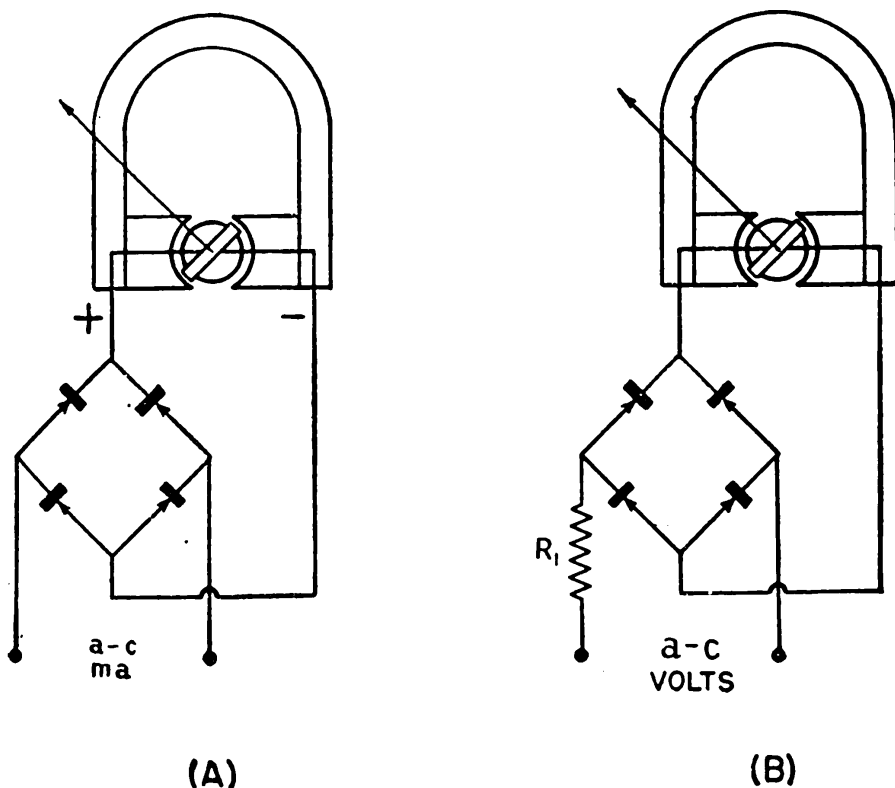


Figure 27.—Copper-oxide rectifier.

meters on a.c., and a-c meters of the moving-vane and dynamometer types use up a lot of juice. The solution—rectify your a.c. into d.c. and measure it with d-c instruments.

Run your a-c power through a COPPER-OXIDE RECTIFIER, figure 27, and you come out with d-c power, ready to measure on a low-power, sensitive d-c moving coil meter. The d-c output of the rectifier is proportional to the a-c input. With the d-c output of the rectifier applied to the d-c meter, you can calibrate the meter to read a-c voltage or current.



The copper-oxide rectifier offers a high resistance to the flow of current in one direction, and a low resistance to the flow in the opposite direction. You get a pulsating d-c output which you can feed to the meter.

The copper-oxide rectifier usually consists of a junction between two dissimilar substances, generally a metal and a crystalline metallic salt which will conduct electricity. This combination offers a comparatively low resistance from the metal to the crystalline metallic salt.

You cannot use the copper-oxide rectifier type meter for the measurement of high-frequency a.c. The high-frequency currents passing through the rectifier generate too much heat. This heat lowers the accuracy of the meter. You will note in figure 27*A* the connection of the line to the rectifier for measurement of current. For the measurement of a-c voltage, insert a resistor  $R_i$  in series with one leg of the line. You can increase the range of the copper-oxide rectifier voltmeter by the use of this multiplier resistor. This is shown in figure 27*B*.

For the measurement of high frequency a-c currents and voltages of low values, you can use a CRYSTAL RECTIFIER type of meter. The operation of this crystal rectifier meter is practically the same as the copper-oxide rectifier. The crystal allows current to pass more easily in one direction than it does in the other. Its application is limited, however, to the measurement of very small currents and voltages.

### VACUUM-TUBE VOLTMETER

You'll have a lot of use for the VACUUM-TUBE VOLTMETER in measuring d-c, a-c, and r-f voltages. The chief advantages of this instrument are the NEGLIGIBLE amount of POWER which the instrument takes from the circuit you're measuring, and GOOD ACCURACY over a wide range of frequencies, even up into the

ultra-high-frequency (u-h-f) range. Here's how it works—

A change in the voltage applied to the grid of a vacuum tube, usually diode or triode, causes a change in plate current. So, if you put the voltage to be measured across the grid circuit, the plate-current CHANGE that results gives you a measure of the ap-

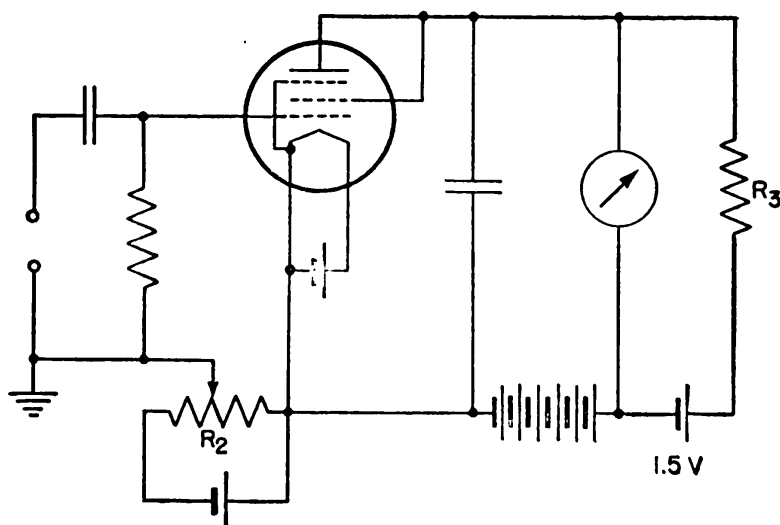


Figure 28.—Vacuum-tube voltmeter.

plied voltage. If you want to measure a-c voltage, the tube rectifies the current, and the voltage measurement is in terms of rectified d-c voltage.

In figure 28, you have the circuit for a FULL-WAVE vacuum-tube voltmeter, which uses a triode. It is designed with its grid-bias operating point above plate cut-off, to allow plate current to flow on both halves of the cycle. Next, look at the plate-current-grid-voltage characteristic curve in figure 29.

In figure 29, you'll see that the outer limits of grid bias range between 0 and  $-3$  volts. Or, the plate current shows cut-off at  $-3$  volts bias, and maximum value at 0 volts. You set the grid bias on a vacuum-tube voltmeter at a point above cut-off to allow plate current to flow on both halves of the a-c voltage cycle. So, you select the point of bias on the curve by picking a point at which the increase in plate current

on the positive half is slightly more than the decrease in plate current on the positive half is slightly more than the decrease in plate current on the negative half. For example, for the 1N5-GT tube in the circuit of figure 29, the GRID-BIAS INTERMEDIATE POINT is 1.4 volts.

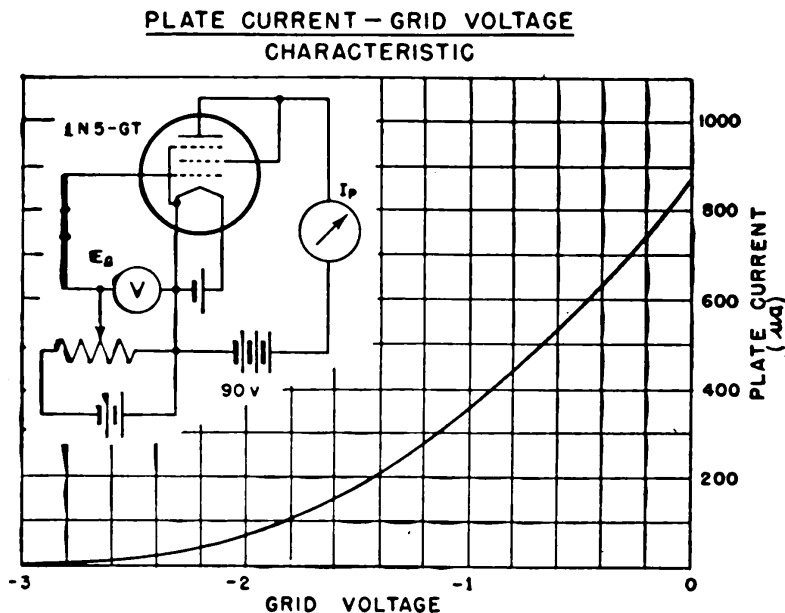


Figure 29.—Characteristic curve of plate current and grid voltage.

Look at the characteristic curve of figure 30, and you'll see that the GRID-BIAS INTERMEDIATE POINT of 1.4 volts is on the curve of the plate-current characteristic. Now refer back to figure 29, and you'll find that for this bias value, you have a plate current of 230 micro-amperes. You can balance the circuit to return the pointer to zero by running a balancing current of this value,  $230\mu$ a, through the meter circuit. Here's how you do it—

Add a 1.5-volt battery and a current-limiting resistor  $R_s$  in shunt with the meter, as shown back in figure 28. You need  $230\mu$ a. as a balancing current, you know the battery voltage, so—

$$R = \frac{E}{I} = \frac{1.5}{230} = 6520\Omega$$

This is the resistance,  $5520\Omega$ , you'll need to get  $230\mu\text{a}$ . balancing current. Adding this resistor and battery to the circuit should bring the needle to zero. Final close adjustments to get EXACTLY ZERO are made on resistor  $R_2$  so that plate current exactly equals balancing current. Then the voltmeter circuit will operate at the correct point on the tube characteristic. The reading is proportional to the effective value of the applied a-c voltage.

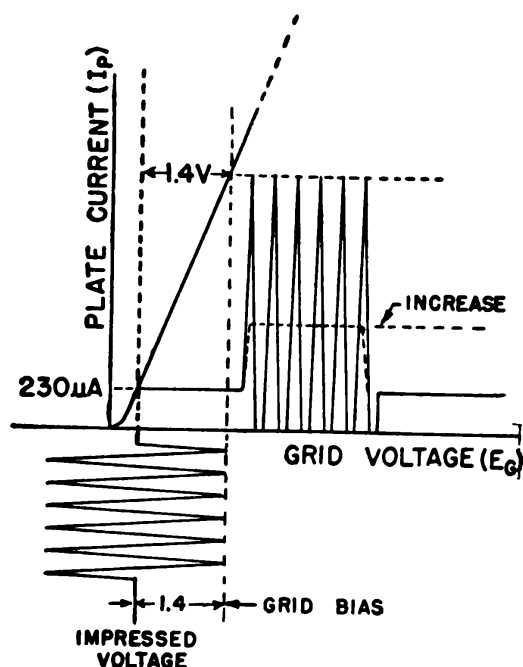


Figure 30.—Characteristic curve with applied a.c.

Here's how to calibrate a full-wave vacuum-tube voltmeter. The same procedure will work with other types of vacuum-tube voltmeters too.

Apply a known a-c voltage to the input of the vacuum-tube voltmeter, and take a plate-current reading. Next look at a calibration chart, such as is shown in figure 31, to see that an applied a-c voltage of 1.0 volt represents about  $150\mu\text{a}$ . plate current. Now take an intermediate voltage of, say, 0.5 volt. The plate current for 0.5 volt will be  $48\mu\text{a}$  on the chart of figure 31. And, by picking various points, you can

read the effective values of voltage for various plate currents from the chart.

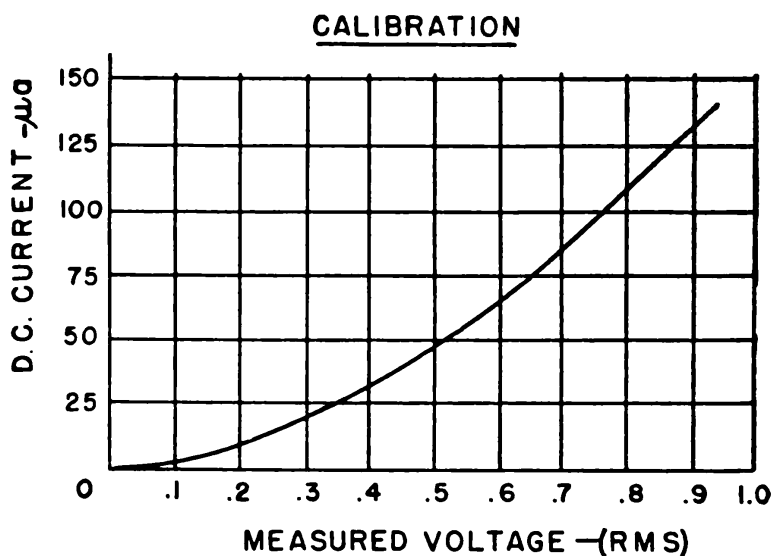
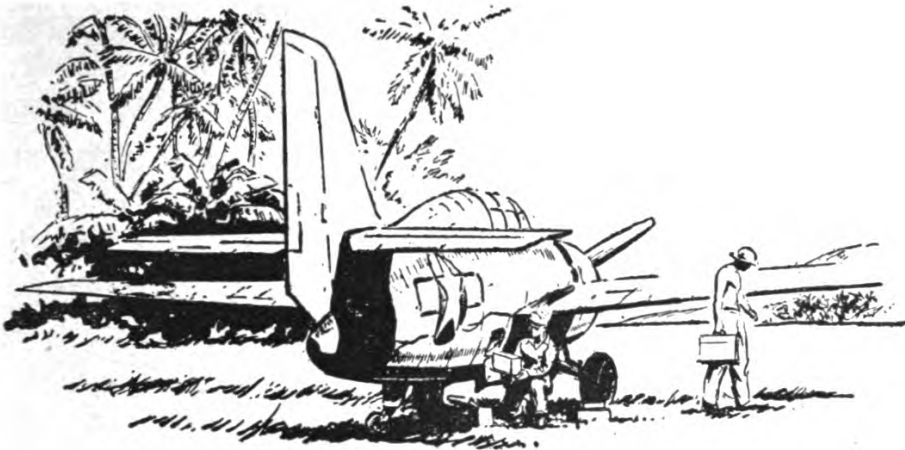


Figure 31.—Calibration chart, full-wave vacuum-tube voltmeter.



### CHAPTER 3

## THEORY OF A-C CIRCUITS

### WHICH TO USE—A.C. or D.C.

You will run into very little a.c. on Navy aircraft, but because of that little, you should know what a.c. is, how it's generated and some of its characteristics. After all, 90 percent of the electricity ashore is a.c.

Now you're probably wondering why we have TWO kinds of current—a.c. and d.c. Why not pick out the better one and toss away the other one? Well, they're BOTH good. For certain jobs, one has advantages over the other.

FOR INSTANCE—

You can generate a.c. at higher voltages than d.c.

You can step-up or step down a.c. with simple stationary transformers, while you have to use complicated rotary motor-generator sets with many moving parts to change the voltage of d.c.

You can transmit a.c. at high voltage over long distances without any great loss of power.

You can build large, high-speed a-c generators that will produce a.c. cheaply and efficiently.

You can use a.c. to run induction motors, which are highly efficient, run at constant speed, and have no complicated commutator. This is a real advantage to the use of a.c. in shops and plants.

BUT—

You still need d.c. for use with electric welding equipment, arc lights, and electro-chemical processes. And you'll need d.c. where you have to use variable-speed motors, such as street-car and electric locomotive motors, elevator and printing-press motors, and other uses. It's much easier to vary the speed of a d-c motor than an a-c motor.

### INDUCED VOLTAGES

You know that a current is induced in a wire when you move the wire through a magnetic field, as in

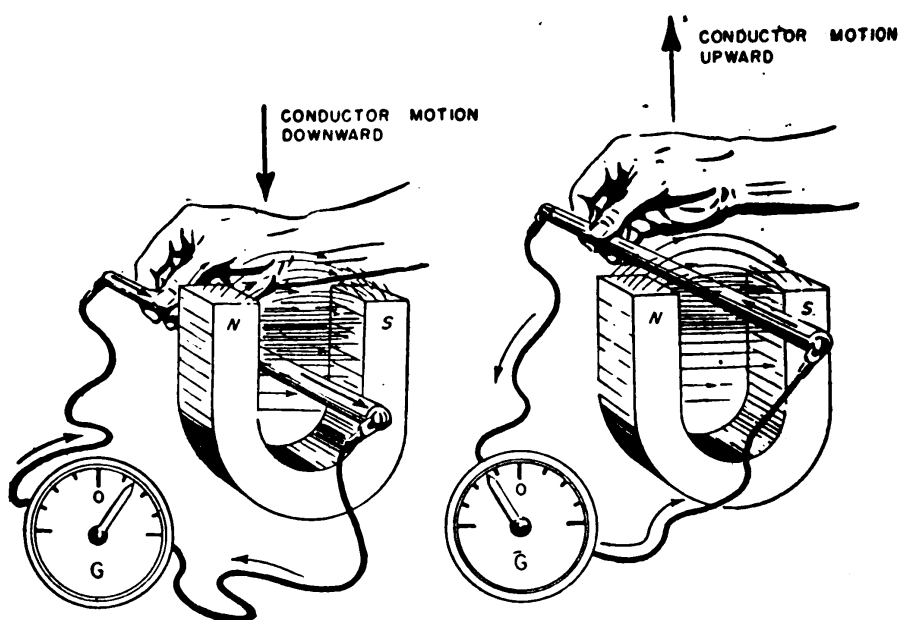
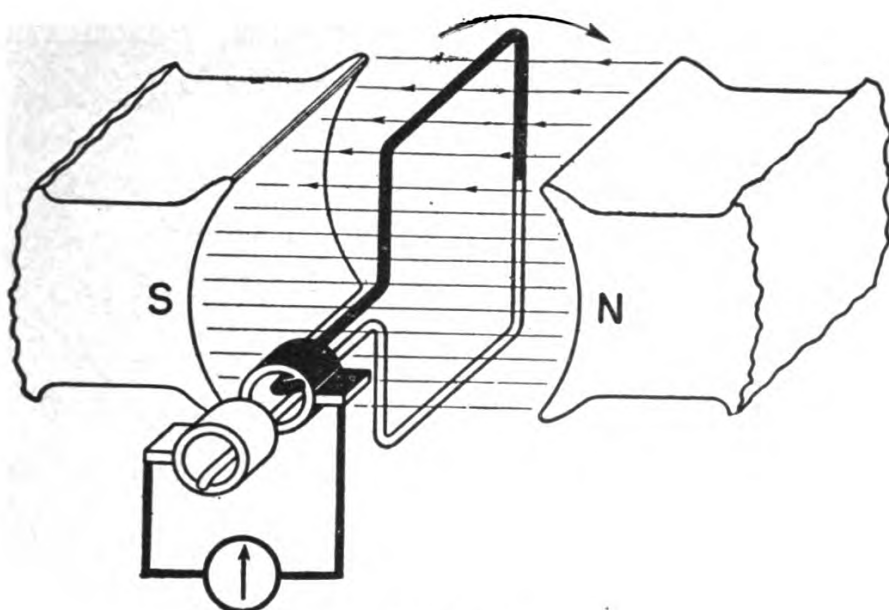


Figure 32.—Induced current in a conductor.

figure 32. If you move the wire DOWN through the magnetic field, the current induced in the wire will flow in one direction. IF you move the wire back UP, the induced current will flow in the opposite direction.

And that's the foundation for the generation of a.c.! It's as simple as that, in theory.

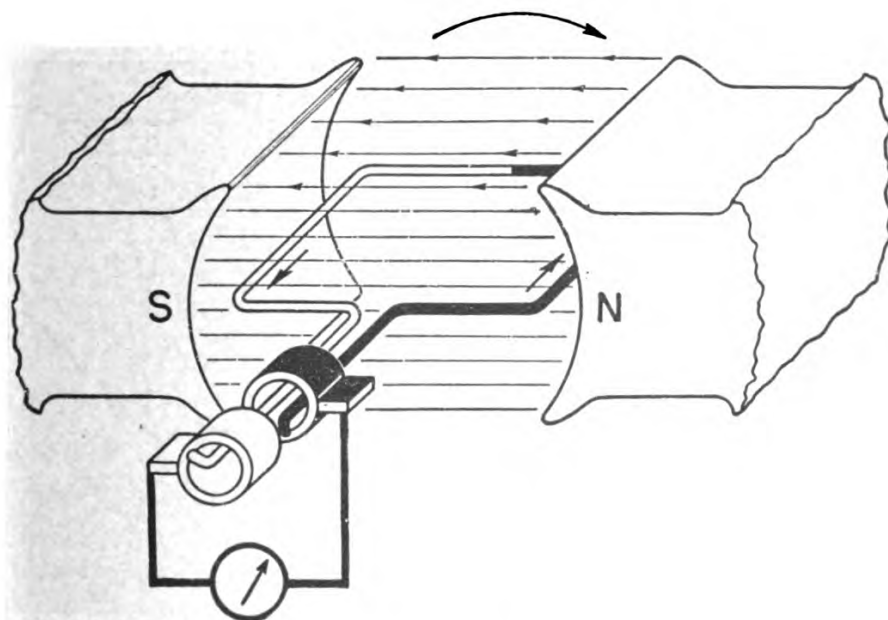
Now look at the stop-motion pictures of a wire loop turning in a magnetic field. They're in figure 33, and you'll quickly recognize them as old friends.



Position 1

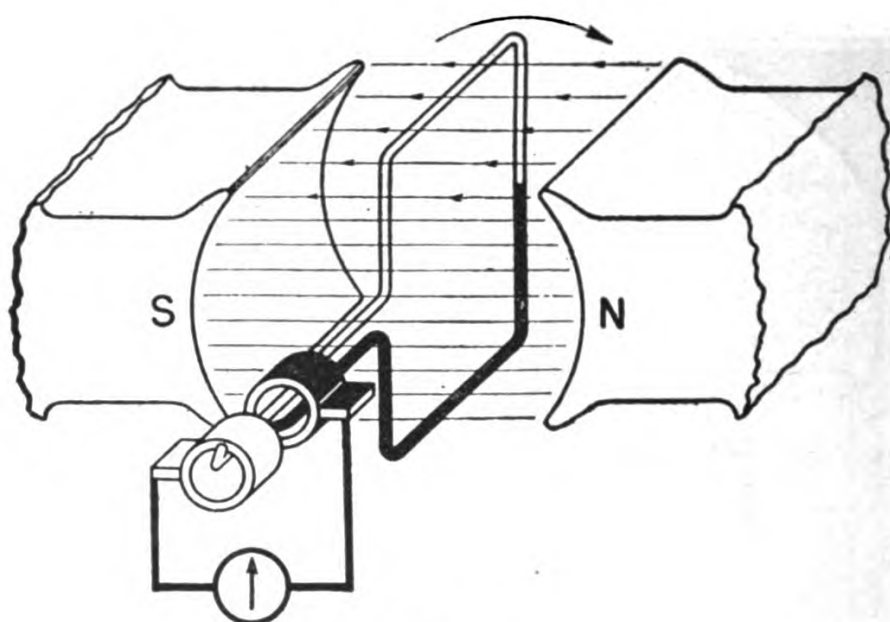
Figure 33.—Rotating loop in magnetic field.

When the loop is in position 1, the conductors are cutting NO lines of flux, so the induced voltage through the loop is ZERO. When the loop moves to position 2, the conductors cut a maximum number



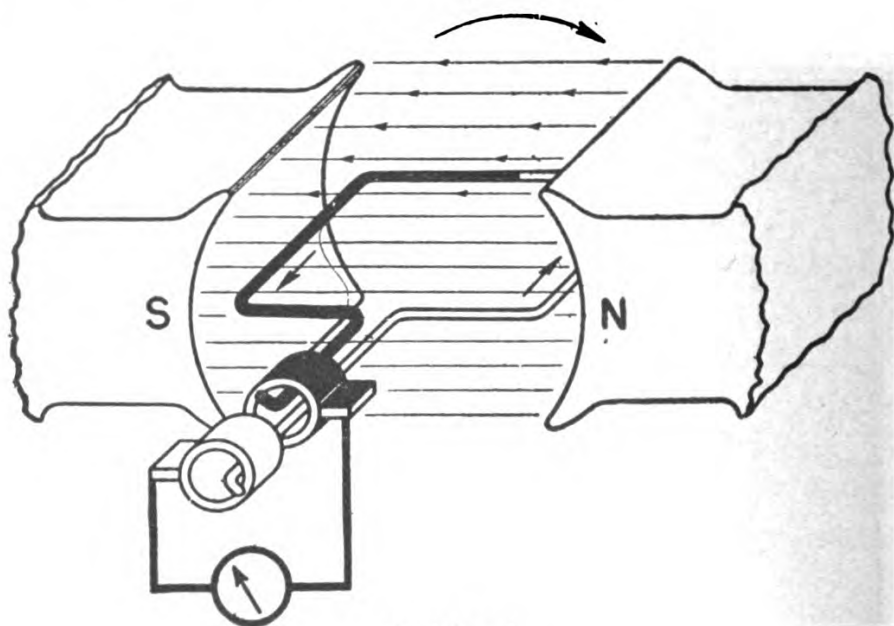
Position 2





Position 3

of lines of flux and voltage through the loop is a maximum positive. Next the loop moves on to position 3, and cuts NO lines of flux, so voltage sinks back to zero. With the loop in position 4, a maximum negative flows through the loop. Then the loop moves on to position 1 again.



Position 4

Now, if you chart the amount of voltage that flows as the loop turns a full revolution, through  $360^\circ$ , you

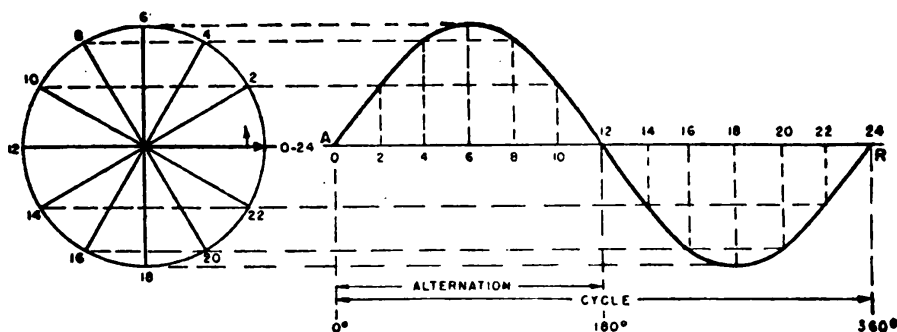


Figure 34.—Sine curve of a-c voltage.

get a curve that looks like figure 34. This is a **SINE CURVE**. You can see that it indicates the induced voltage at any given point in the rotation of the loop.

### CYCLES AND FREQUENCIES

You may remember that the electricity at home is 110 volts, 60-CYCLE, a.c. The “60-cycle” means that it has a **FREQUENCY** of 60 cycles per second. Or the current and voltage change their direction twice per cycle, or 120 times a second. You see, the current in the single-loop conductor of figure 33 goes from zero to maximum positive to zero in  $180^\circ$  or a half rotation of the loop. Then current goes from zero to maximum negative and back to zero in the second half of the rotation. The loop has completed a cycle, and the induced current has made **TWO** alternations.

The current or voltage makes a complete cycle every time it passes a pair of poles (a north and a south pole). In the simple one-loop generator, you have only one pair of poles, so one revolution of the loop makes one cycle of current induced. Two pairs of poles would let you generate **TWO** cycles of induced current per revolution of the loop.

To generate 60-cycle current, a machine having a single pair of poles would have to rotate at—

$$\begin{array}{ccccc} 60 & \times & 60 & = & 3,600 \\ \text{(cycles per} & & \text{(seconds per} & & \text{(revolutions per} \\ \text{second)} & & \text{minute)} & & \text{minute)} \end{array}$$

A machine with TWO pairs of poles (called a 4-pole machine) would have to turn only half as fast to generate the same 60-cycle frequency, since ONE revolution of this machine generates TWO cycles.

And so you get a formula for FREQUENCY. If you know the speed,  $V$ , of the machine in rpm and the number of PAIRS of poles ( $P$ ) in the machine, the generated frequency,  $F$  will be equal to

$$F = \frac{PV}{60}$$

For example, a 2-pole machine has ONE PAIR of poles, and rotates at 3,600 rpm. What's its frequency?

$$F = \frac{1 \times 3,600}{60} = 60 \text{ cycles (per second)}$$

If you know how many cycles you want to get out of a certain machine, but need to find out HOW FAST the machine must turn to generate 60-cycle voltage, turn the formula around so that—

$$V = \frac{60F}{P}$$

For example, in a 4-pole machine (2 pairs)—

$$V = \frac{60F}{P} = \frac{60 \times 60}{2} = 1,800 \text{ rpm.}$$

#### EFFECTIVE VALUE OF A.C.

If you want to find out what is the EFFECTIVE or usable value of a.c. from your sine curve, you can't

just glance at the highest peak of one loop of the sine curve. The voltage or current charted by the sine curve is changing throughout the alternation from a value of zero to maximum and back to zero. Result—you have to determine the EFFECTIVE value of the a.c. If you take the PEAK value of current or voltage—that highest point to which your sine curve climbs or drops before it turns back down or up—

and multiply that value by  $\frac{1}{\sqrt{2}}$  or roughly 0.7,

you'll come out with the EFFECTIVE value of the a.c. Or perhaps you know the effective voltage of the machine, and need to get the peak or maximum voltage. Multiply the effective voltage by 1.414, and you'll get the peak voltage.

For example, the sine curve for a certain a-c generator reaches a peak voltage of 110 volts. Then the effective voltage will be  $0.7 \times 110 = 77$  volts. In other words, your 110-volt a-c generator will generate an effective voltage capable of producing the same amount of POWER as would be produced by a 77-volt d-c generator.

You likewise use 0.7 as the multiplier for obtaining EFFECTIVE CURRENT when you know PEAK CURRENT.

### CURVES IN PHASE

When you are walking in step with your girl, the two of you are in PHASE: but if she's taking  $1\frac{1}{2}$  steps to your one, you're OUT OF PHASE. Since the voltage of an a-c generator causes the current to flow, the sine waves of current and voltage drawn or plotted on the same sheet will be a pair of curves that are in PHASE, as in figure 35. That is, the curves cross the zero line together, and then reach their peaks at the same point of conductor rotation.

Actually, engineers usually design a-c generators and motors to operate so that the voltage reaches its

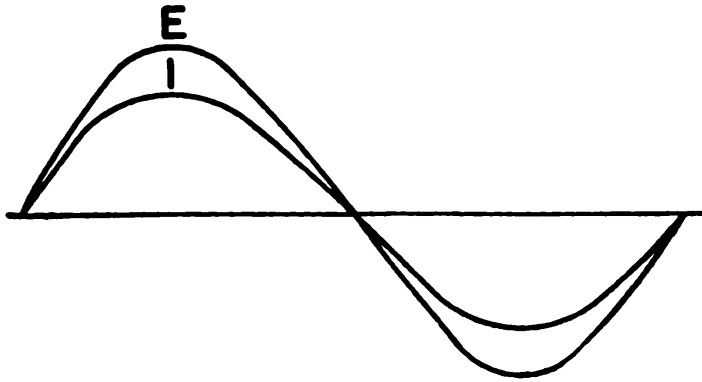


Figure 35.—Voltage and current curves in phase.

peaks and zeros BEFORE or AFTER the current does. Then you say that the voltage is OUT OF PHASE with the current. If the current curve reaches its peaks and zeros BEFORE the voltage curve, then the current is LEADING the voltage, and the voltage is LAGGING the current. By measuring the number of degrees of rotation that has taken place between the time the leading curve crosses zero and the lagging curve crosses zero, you can find out how many DEGREES OUT OF PHASE the two curves are. For example, in

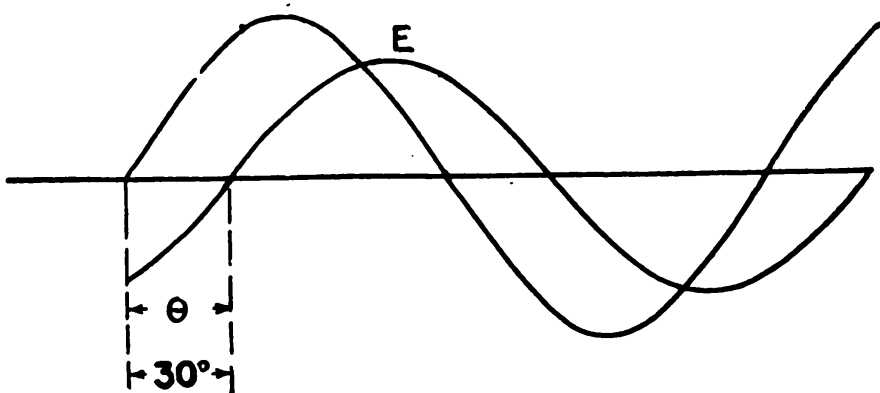


Figure 36.—Voltage curve  $30^\circ$  out of phase with current curve.

figure 36, the current and voltage are out of phase, and the voltage LAGS the current by  $30^\circ$ , or the current

LEADS the voltage by  $30^\circ$ . You can also describe this condition by saying that the PHASE ANGLE is  $30^\circ$ . And the symbol for phase angle is  $\Theta$  (Greek letter THETA).

## VECTORS, AND WHAT THEY DO

Mathematicians have developed a mighty handy means to enable you to add FORCES together easily and quickly. The name for this method is VECTOR ADDITION. VECTORS are simply lines drawn to scale and in the proper direction to indicate the intensity and direction of the forces you want to add or subtract. For example, suppose a vector 1 inch long represents a force of 10 pounds or perhaps 10 volts. Then a 2-inch vector would represent a force of 20 pounds or 20 volts. You will use vectors and vector diagrams to analyze alternating currents and their emf's.

Suppose you have a small wagon loaded with batteries and tools that you want pulled across the hanger apron to a plane, and you find two men who want to help. The bigger fellow can pull 80 pounds, and the little guy can pull 50 pounds. But they get their planes mixed—the little guy thinks you want the tools at a plane that's parked *NNE* of the tool room, while the big boy heads for a plane straight *E* of the tool room. What to do? Either let them pull and tug together in different directions, or throw them off the job and get one great big guy who can go in the right direction. Let's figure out by vectors what size man you'll need, and what his compass course will be. Look at figure 37.

Here's what you do. Lay out a scale diagram of the situation, with line *OA* representing the compass course and amount of pull of the little fellow. *OA* will be 5 units long, each unit representing 10 pounds of pull. Line *OC* represents the pull of the big guy and his path to the east, and is 8 units long, for 80

pounds total pull. Now you have two vectors—the one for the little man and the one for the big guy.

To get rid of the two men and replace them with one great big guy pulling in the right direction, you now lay  $AB$  parallel to  $OC$  and of the same length as  $OC$ . Then lay off  $CB$  parallel to  $OA$  and of the same length as  $OA$ . Draw the diagonal line  $OB$ . That gives you the direction and the amount of pull your new man will have to exert. If you measure

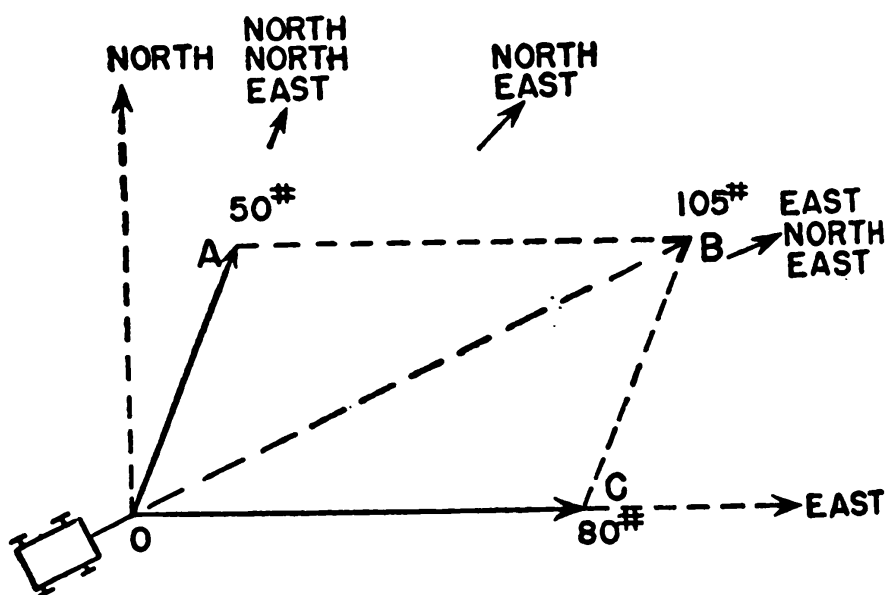


Figure 37.—How vectors add.

the length of  $OB$  you'll find that it is  $10\frac{1}{2}$  units, meaning that your new boy will have to be able to pull 105 pounds on a course a little north of *ENE*.

You see that you've solved a pretty complex problem without using a bit of math.

## VECTORS AND SINE WAVES

And here's how vectors work in dealing with a.c. Look at figure 38, which is a combination of a SINE CURVE and a VECTOR DIAGRAM for a single loop armature rotating in a magnetic field and generating a peak voltage of 10 volts.

When the conductor is at  $0^\circ$ , or 3 o'clock position, it is cutting no lines of flux in the magnetic field, and is generating no induced voltage. When the conductor moves up to  $30^\circ$ , or the two o'clock position, an induced voltage of 5 volts is generated, and finally when the conductor reaches  $90^\circ$ , or 12 o'clock position, the peak voltage of 10 volts is induced.

You can see that if you allow your vector arrow to rotate along with the inductor, and then run a

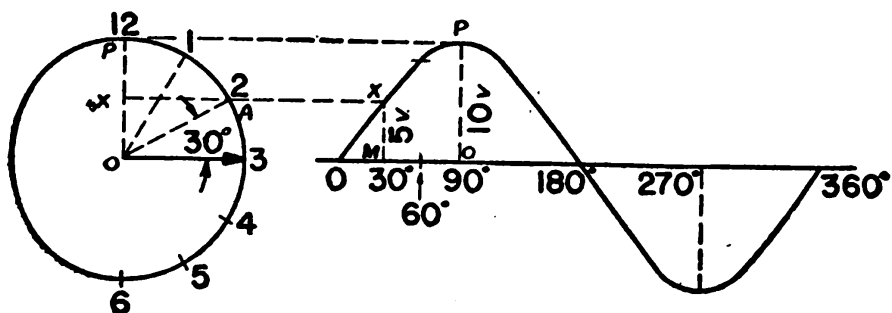


Figure 38.—Vector diagram and sine curve.

horizontal line from the arrowhead over to the line of peak voltage, such as line  $XY$  from 2 o'clock position, you will be able to find the voltage at the 2 o'clock position. Just measure the length of line  $OX$ . It's half the length of  $OP$ , and  $OP$  represents the peak voltage of 10 volts, so  $OX$  must be 5 volts.

### VECTORS AND A.C.

Now we come to the real use for vectors—as an easy way to analyze a.c. without struggling with tough mathematics.

Suppose you have an armature with TWO conductor loops on it—loop  $B$  being  $30^\circ$  behind loop  $A$ . When you rotate this two-loop armature in the magnetic field, loop  $A$  will be cutting a maximum number of lines of flux when loop  $B$  is only cutting about  $\frac{3}{4}$  of the maximum as in figure 39. Hence  $A$  will generate peak voltage, while  $B$  generates 70 percent of peak voltage.



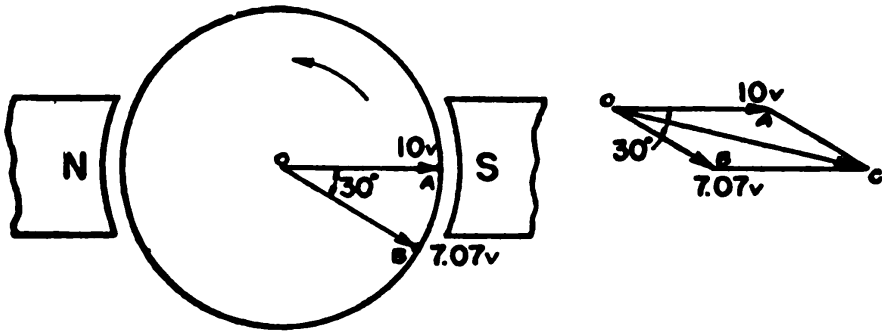


Figure 39.—Two-loop armature and its vector diagram.

Here's how to add these two voltages with vectors. The peak voltage of the generator is 10 volts, so lay off a line  $OA$ , in figure 39, 1 inch long to represent 10 volts. Your vector scale is  $1'' = 10$  volts.

Then lay off a line  $OB$  at an angle of  $30^\circ$  to  $OA$ , but make  $OB$  only  $\frac{3}{4}''$  long to indicate 7.5 volts. Next, build up a parallelogram by making  $AC$  equal and parallel to  $OB$ , and  $BC$  equal and parallel to  $OA$ . Then draw the diagonal  $OC$ . Measure its length, which turns out to be  $1\frac{6}{8}$  inches, or 16.95 volts. And that gives you the resultant emf of the two voltages.

### OTHER VECTOR TRICKS

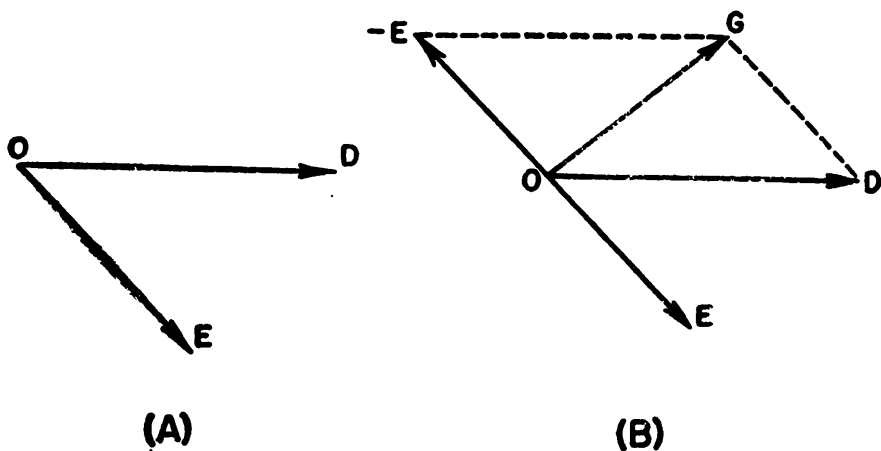


Figure 40.—Vector subtraction by parallelogram.

Here are some other things you can do with vectors. You can subtract one value from another with vectors, as in figure 40. You want to subtract vector  $OE$  from vector  $OD$ . So you reverse the direction of  $OE$  to get MINUS  $OE$  and then construct the parallelogram. The resultant vector,  $OG$ , gives you the scale and direction of the difference of the two vectors.

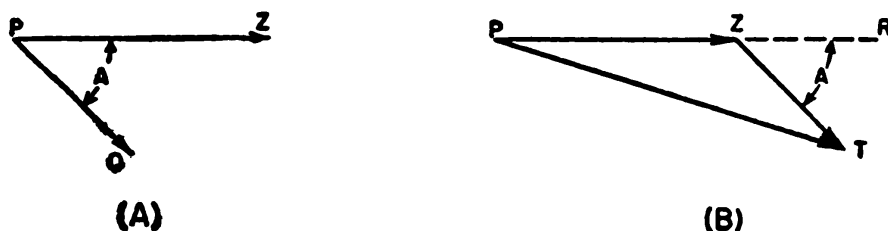


Figure 41.—Vector addition by triangles.

And here's a short-cut. You don't need to construct the parallelogram each time to get the resultant vector. Just make a TRIANGLE, as in figure 41, and your resultant will give you the length and direction of the vector. Here's how the triangle method works.

Lay off one vector,  $PZ$ . Then from the arrowhead of  $PZ$ , lay off your second vector  $ZT$  (equal in length to  $PQ$ ), making the correct angle  $A$  between  $PZ$  and  $ZT$ . Now connect  $P$  to  $T$ , and  $PT$  is the resultant vector of the addition of vectors  $PZ$  and  $PQ$ .

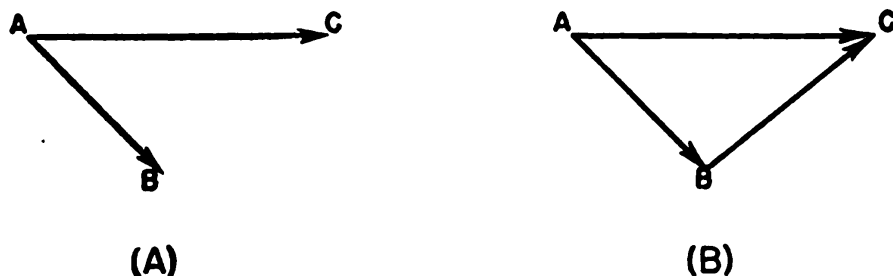


Figure 42.—Vector subtraction by triangle.

And here's the method for SUBTRACTING vectors by triangles. Look at figure 42. You want to subtract vector  $AB$  from vector  $AC$ . Lay off the two vectors

$AB$  and  $AC$  in the proper directions and to the proper scale. Then, you say to yourself "Take  $AB$  FROM  $AC$ " and you move out along the first vector or  $AB$  to the arrow head. Then draw a line FROM that arrowhead to the arrowhead of the second vector  $AC$ . The resultant  $BC$  is the vector difference of  $AC-BC$ . But—

If you were subtracting  $AC$  from  $AB$ , you'd move out  $AC$  to the arrowhead, then draw a vector FROM  $C$  to  $B$ . Your resultant arrow would now be  $CB$ , not  $BC$  as before. Direction of the resultant has been REVERSED.

So much for the theory of vectors. Next, you'll see how much they can simplify your analysis of a.c.

### VECTOR ANALYSIS OF A.C.

In figure 43, you see two alternating currents,  $I_1$  and  $I_2$ , plotted as sine waves.  $I_1$  has an effective current value of 16 amps, and  $I_2$  has an effective value of 10 amps and also LAGS  $I_1$  by  $60^\circ$ . First you need to find the MAXIMUM current values of  $I_1$  and  $I_2$ . Multiply their effective values by 1.414—

Then  $I_1 \text{ max} = 16 \times 1.414 = 22.62 \text{ amps.}$

And  $I_2 \text{ max} = 10 \times 1.414 = 14.14 \text{ amps.}$

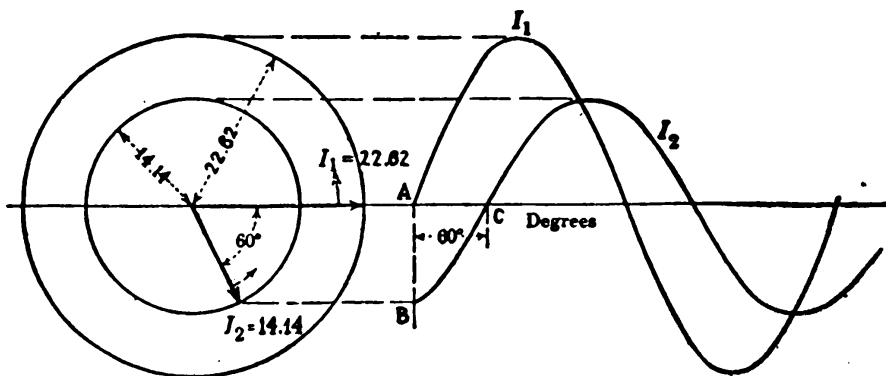


Figure 43.—Sine waves drawn from vectors.

Next, draw two circles, one with a radius to a scale of 22.62, and the other with a radius to a scale

of 14.14. Now, remembering that  $I_2$  lags  $I_1$  by  $60^\circ$ , you are ready to rotate the two radii COUNTERCLOCKWISE, and project their lengths horizontally across to produce two sine waves,  $I_1$  and  $I_2$  in figure 43. You'll see that these waves automatically come out  $60^\circ$  out of phase, since you have laid out the vectors  $60^\circ$  out of phase. Always remember to ROTATE YOUR VECTORS COUNTERCLOCKWISE. The electrical engineers all over the world have agreed to use counterclockwise rotation so that their diagrams would be uniform and easy to understand.

Next, suppose you want to feed the two currents  $I_1$  and  $I_2$  into a line. You must know what current flows in that line at various instants. If they were d.c., you'd have no trouble. You'd just add 10 to 16, and get a total of 26 amps. But it's not so easy with a.c.  $I_1$  is zero when  $I_2$  is  $-11.3$  amps., and so on around to the instant when  $I_1$  is a maximum 22.62 amps. and  $I_2$  is building up towards its maximum. Now here's where you'll really be glad you know about VECTOR ADDITION.

You could labor through and plot the two sine curves  $I_1$  and  $I_2$ , and then struggle with measuring off their respective values at various instants. And eventually you'd come up with a curve that looks somewhat like  $I_3$  in figure 44A.

Want to do it the easy way? All right, use the parallelogram method you learned earlier in this chapter. In figure 44B, you have an enlarged sketch of the parallelogram that is shown much smaller in figure 44A. See what you do? Lay off line  $AB$  horizontally and to a scale of 22.62 amps. for  $I_1$ . Then lay off  $AC$ , making LAG angle of  $60^\circ$  with  $AB$ , and to a scale of 14.14 amps. for  $I_2$ . Next, construct the parallelogram  $ABCD$  around the vectors  $AB$  and  $AC$ . Finally, draw the diagonal  $AD$ , scale it

off, and you find that—

$I_1 + I_2 = I_3 = 32.19$  amps., maximum current for  $I_3$ . You also find automatically that  $I_1$  leads  $I_3$  by angle  $\theta$ , on figure 44B.

Next draw a third circle of radius 32.19 amps., scale around the circles  $I_1$  and  $I_2$  on figure 44A, and

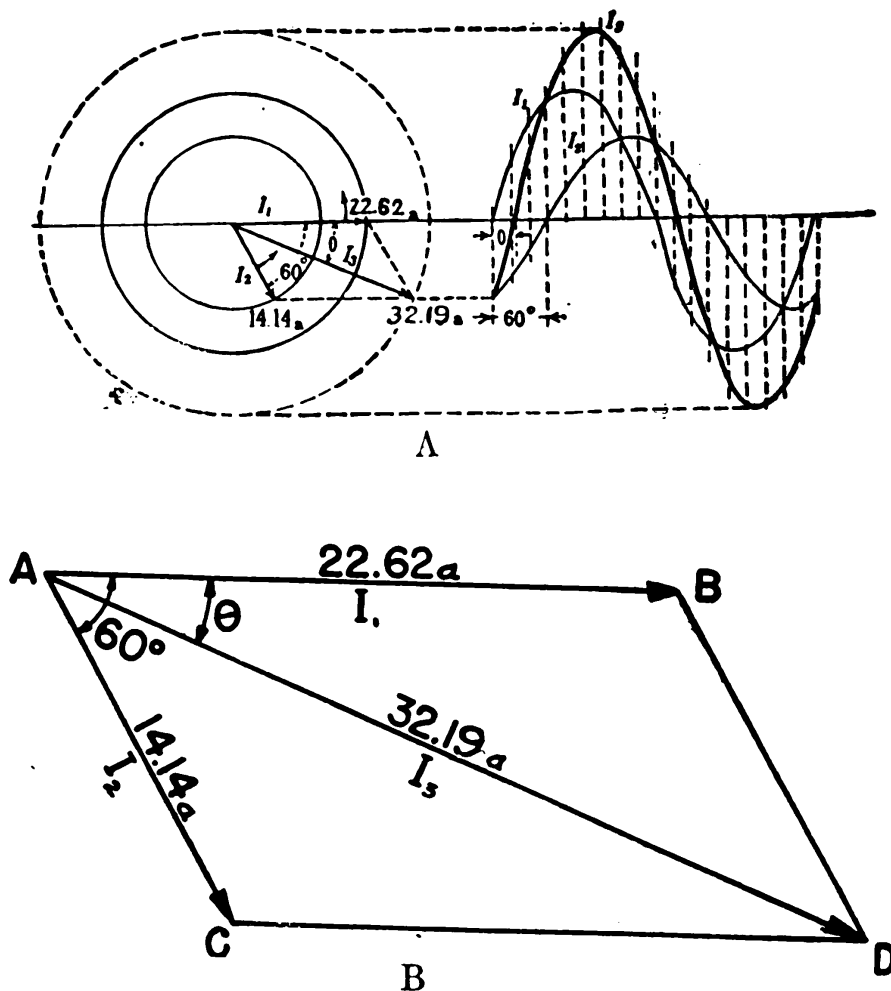


Figure 44.—Vector addition of two a-c currents.

you can readily construct the sine curve for  $I_3$  as your alternating currents.  $I_1$  and  $I_2$  vary from maximum positive through zero to maximum negative, and back again.

And now since you know that the EFFECTIVE values of  $I_1$  and  $I_2$  are 16 and 10 amps., respectively, you'll

want to know the EFFECTIVE value of  $I_s$ . Just multiply the MAXIMUM value of  $I_s$ , which you found by vector addition to be 32.19 amps., by 0.707—

$$I_{s\text{eff.}} = I_{s\text{max.}} \times 0.707 = 32.19 \times 0.707 \\ = 22.75 \text{ amps.}$$

Of course, you can also solve the problem of the EFFECTIVE voltage of  $I_s$  vectorially, without bothering with the MAXIMUM voltages. Lay off a horizontal line to represent  $I_{1\text{eff.}}$  to a scale of 16 amps. Then lay off at a LAG angle of  $60^\circ$  a second line to represent  $I_{2\text{eff.}}$  construct a parallelogram around  $I_1$  and  $I_2$ . The diagonal will give you  $I_s$ , which you can measure to discover that  $I_{s\text{eff.}} = 22.75$  amps.

### REMEMBER THIS !!

You must combine ALTERNATING voltages and currents by VECTORS. There is no other way to do it.

### A PROBLEM IN A.C.

Got time for a problem to test your brains on vectors?

PROBLEM: You have an a-c generator,  $A$ , which produces an effective current of 100 amperes. You have a second a-c generator,  $B$ , producing an effective current of 60 amperes, and operating  $45^\circ$  out of phase, lagging, with the first generator. If you feed the output of these two generators into a line, what effective current will you get from the line?

SOLUTION: Figure 45 gives you the vector diagram and sine curves.

### A-C POWER

You remember that d-c power is the product of voltage and current. The same formula—

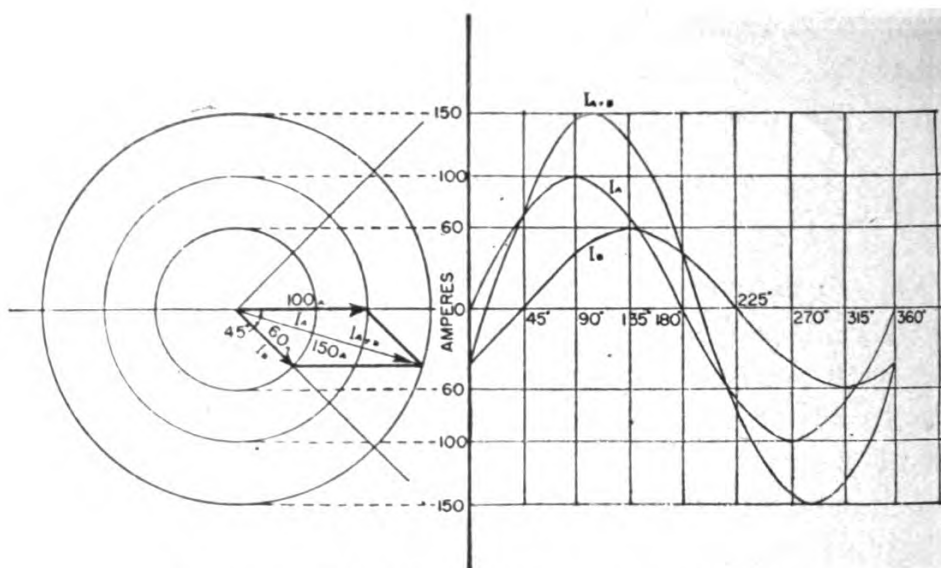


Figure 45.—The problem of the two a-c generators.

$$P = EI$$

can be used with the INSTANTANEOUS values of  $E$  and  $I$  for a.c. to obtain INSTANTANEOUS POWER, but you do not necessarily get the AVERAGE power if you multiply the EFFECTIVE current and EFFECTIVE voltage together.

### VOLTAGE AND CURRENT IN PHASE

Suppose you had voltage  $E$  in phase with current  $I$ , as in figure 46. In the first half of the cycle,  $E$  and  $I$  are both positive. So  $P_{\text{instantaneous}}$  is positive, reaching its peak along with  $E_{\text{inst.}}$  and  $I_{\text{inst.}}$ , which are in phase. Then the curves of instantaneous values for  $E$ ,  $I$ , and  $P$  all hit zero together. In the next alternation, both  $E$  and  $I$  go negative. But multiplying  $-E$  by  $-I$  gives you  $+P$ , so the power curve rolls up again to a maximum POSITIVE at the same instant that  $E$  and  $I$  reach a maximum NEGATIVE. As long as  $E$  and  $I$  are in phase, the power curve  $P$  will always be POSITIVE and will also be a

sine curve with TWICE the frequency of the  $E$  and  $I$  curves.

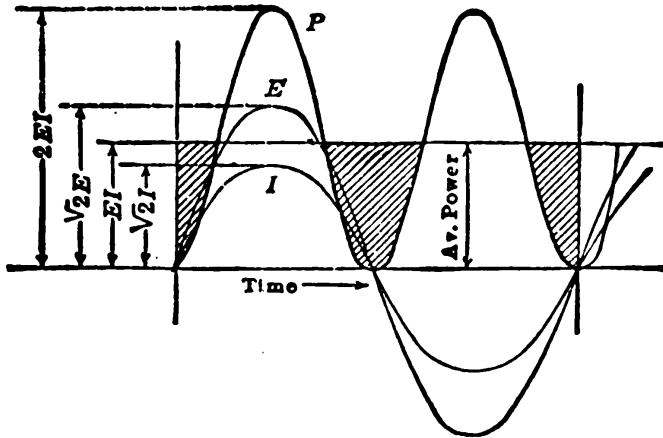


Figure 46.—Power curve;  $E$  and  $I$  in phase.

The PEAK of the power curve  $P$  can be found by using the formula—

$$P_{max} = (\sqrt{2} \times E_{max}) (\sqrt{2} \times I_{max}) = 2E_{eff} \times I_{eff}$$

where  $E_{eff}$  and  $I_{eff}$  are the EFFECTIVE values of voltage and current.

You can see that if you run a line through the power sine curve at a distance  $EI$  above the zero line, the peaks of the curves above this line  $EI$  will just properly fill in the shaded valleys between the loops of the power curves in figure 46. Then if you take the AVERAGE HEIGHT of the power loops as being  $EI$ , marked on figure 46, you'll be able to solve problems of a.c. in phase. For instance—

### THIS PROBLEM

You have a string of regular Mazda lamps. The whole string draws 30 amps. at 110 volts, 60 cycles. How much POWER do the lamps use? This type of load is IN PHASE.

Use the formula

$$P_{max} = E_{eff} \times I_{eff} = 110 \times 30 = 3,300 \text{ watts. (Ans.)}$$



See how you solve a.c. IN PHASE just as you solve d.c.? BUT—a.c. OUT of phase is something else!

### A.C. OUT OF PHASE

Now look at a case when a-c voltage LEADS the current by  $\theta^\circ$  phase angle. You have the diagram in figure 47. The phase angle,  $\theta^\circ$ , is more than  $0^\circ$  and less than  $90^\circ$ .  $P$  is the power curve.

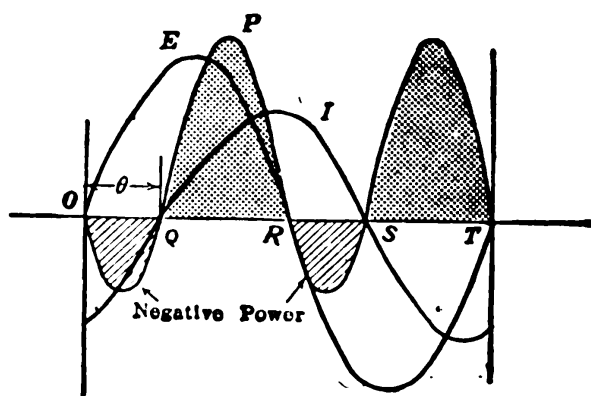


Figure 47.—Power curve  $E$  is  $\theta^\circ$  out of phase with  $I$ .

At points  $O$ ,  $R$ , and  $T$ , VOLTAGE becomes zero, while at points  $Q$  and  $S$ , CURRENT is zero. Because of this zero value in your multiplication, the value of power curve  $P$  is zero at ALL these points. Between points  $O$ - $Q$  and  $R$ - $S$ , voltage is POSITIVE and current is NEGATIVE, so your power curve is NEGATIVE between these points. But between  $Q$ - $R$  and  $S$ - $T$ , both voltage and current are positive, so your power curve  $P$  rises to POSITIVE loops.

You can easily see that the positive power loops—shown dotted—have greater area than the negative power loops—shown cross-shaded. And your average power is a positive quantity, but is less than  $E \times I$ . You can use this information to make up a formula.

$$P_{av} = EI \cos \theta$$

If you know the phase angle,  $\theta$ , you can find out

the cosine of  $\theta$  in any trigonometry book.  $P$  gives you true power or true watts, and  $EI$  gives you the apparent watts or volt-amperes. The cosine  $\theta$ , usually written "cos  $\theta$ ," gives you the POWER FACTOR of the machine or transformer.

Suppose you need to know the power factor of an a-c machine or a transformer. You can get it thus—

$$\text{Power Factor or P.F.} = \frac{P}{EI} = \cos \theta$$

Remember, though—you can never have a P.F. that is GREATER than 1, or UNITY, as the mathematics men call "one". The best phase angle you can get is  $0^\circ$ , when  $E$  and  $I$  are in phase, and the cosine of  $0^\circ$  is 1.000. So don't try to get a P.F. bigger than 1.0, or you'll have a weird kind of generator.

#### A PROBLEM

Suppose you have an a-c generator with voltage leading current by  $37^\circ$ . What's the P.F.?

$$\text{P.F.} = \cos \theta = \cos 37^\circ = 0.80$$

so your generator has an 80 percent power factor.

#### RESISTANCE IN A-C CIRCUIT

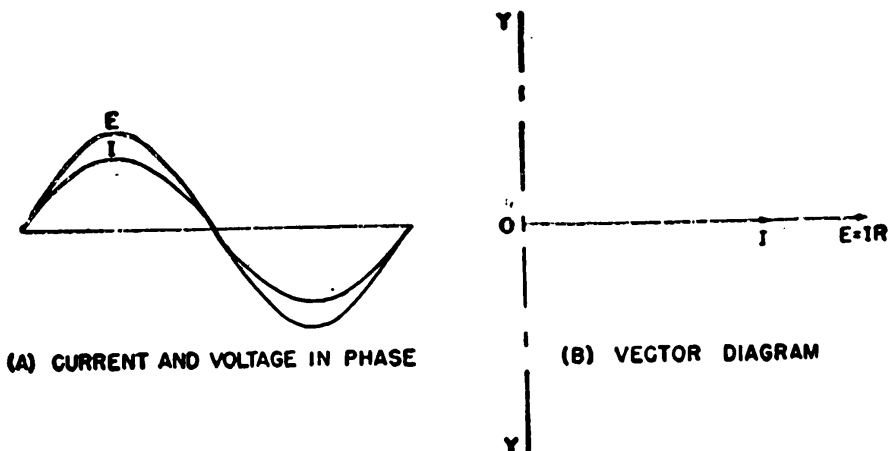


Figure 48.—Vector diagram of resistance

An a-c circuit that contains RESISTANCE only can be treated exactly like a d-c circuit. That is, the formula for power is the same—

$$P = EI = I^2R$$

A vector diagram, figure 48, shows that  $E = IR$ , and that  $IR$  drop or voltage is equal to the voltage  $E$ , and is in phase with the current  $I$ .

### INDUCTANCE IN A-C CIRCUIT

You remember what INDUCTANCE is—the opposition of a current to any change, whether large or small. When you handle d.c., inductance is of little importance, since change in direction or volume occurs only infrequently, as when the circuit is opened or closed. But a.c. changes direction 60 cycles a second or even more frequently. Hence inductance becomes of great importance in the study of a.c.

Look at figure 49A, which shows the voltage

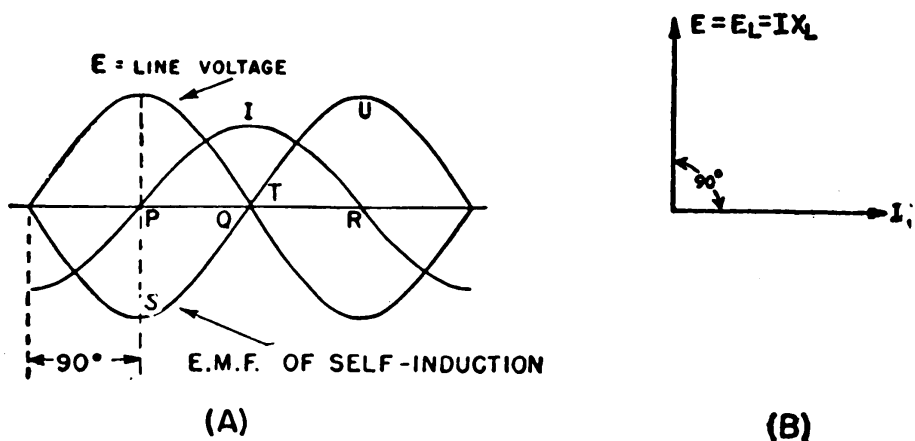


Figure 49.—Current and Voltage relationship.

curve, current curve, and inductance curve for an a-c circuit containing pure inductance with no resistance. Notice that the current curve,  $I$ , is at maximum rate of change at point  $P$ , where the current changes from negative to positive. So that's where

you'd expect MAXIMUM INDUCTANCE or resistance to change. And since the current is changing from negative to positive, you'd expect the inductance to be maximum negative. All right, put on point *S* at the same instant of time as point *P*, and make *S* maximum negative. Next, at time *Q*, the current curve reaches its peak, and levels off for a split-second, its rate of change being zero. So you'd expect the inductance at that instant to be zero, which it is. Your inductance curve will go through zero at time instant *Q*.

Next, the current undergoes a maximum change from positive to negative at instant *R*, and so you'd expect the inductance to reach a maximum positive value at that instant to oppose the maximum rate of change of curve *I* from positive to negative.

You can now draw a sine curve for the values of inductance opposing the a.c. The inductance curve will have the same FREQUENCY as the current curve, but will be  $90^\circ$  out of phase, LAGGING. The current curve LEADS the inductance curve by  $90^\circ$ .

The LINE VOLTAGE, *E*, has to overcome the inductance *emf*, or no current will flow in the a-c circuit. Hence, curve *E* of line voltage will be equal in value to curve *X* of inductance, but will oppose it in order to cancel it out. Thus, on the sine curve diagram in figure 49A you will add curve *E*, which is maximum POSITIVE at the instant that curve *X* of inductance is maximum NEGATIVE. Both are zero together, and *E* is maximum negative when *X* is maximum positive. Curve *E* is  $180^\circ$  out of phase, leading with curve *X*.

Now you can see that your imaginary circuit which contains only inductance, with no resistance, has its voltage LEADING the current by  $90^\circ$ . So you can draw the vector diagram of figure 49B, with arrow *E* leading arrow *I* by  $90^\circ$ .

The symbol for inductance is *L*, and the unit of inductance is the HENRY.

In this imaginary circuit having inductance only, the current is directly proportional to voltage, and is inversely proportioned to frequency and self-inductance. A formula shows this—

$$I = \frac{E}{2\pi fL}$$

where  $2\pi f$  is the frequency, and  $L$  is the self-inductance.

The choking effect or the resistance to the flow offered by inductance is represented in the formula by  $2\pi fL$ , and is called the **INDUCTIVE REACTANCE** of the circuit. The symbol for inductive reactance is  $X_L$ , and its unit is the *OHM*. Thus the voltage impressed on the circuit is—

$$E = 2\pi fLI = IX_L$$

Here's a problem—

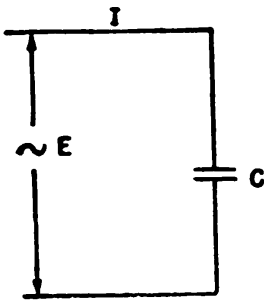
A pure inductance of 0.3 henry is connected across a 110-volt, 60-cycle feeder. How much current flows?

$$I = \frac{E}{X_L} = \frac{E}{2\pi fL} = \frac{110}{2\pi 60 \times 0.3} = 0.973 \text{ amp. (ans.)}$$

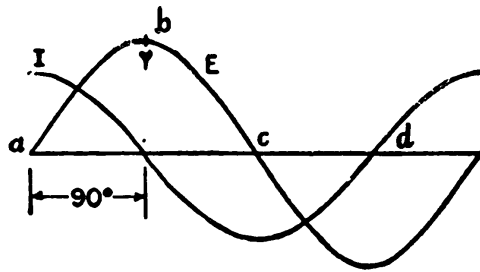
### CAPACITANCE IN A-C CIRCUIT

You remember how a condenser works in a d-c circuit. When you close the circuit, the current rushes into the condenser and charges it to line potential. Then while the voltage remains constant, there is no further current flow. Open the circuit, however, and make the voltage zero. Then current will flow FROM the condenser. But when you feed a.c. to a condenser, you are charging and discharging the condenser many times per second, and condenser behavior becomes very important.

In figure 50A, you see a circuit with an a-c voltage impressed across a condenser  $C$ . At instant  $a$ , the a-c voltage is crossing the zero voltage line and rising to a positive value. The condenser is being charged with positive current flowing from the positive wire into the condenser. This flow will continue as long



(A)



(B)

Figure 50.—Circuit containing capacitance.

as the voltage across the condenser is increasing. At instant  $b$ , however, the voltage starts dropping back to zero, and the current in the condenser becomes zero. From instant  $b$  to  $c$ , voltage is dropping, so current flows OUT of the condenser INTO the circuit. Since the current flow has now reversed its direction, it is **NEGATIVE**. Its curve drops below zero line of the sine wave diagram, to become maximum **NEGATIVE** at instant  $c$ .

At instant  $c$ , the voltage crosses the zero line in its alternation and becomes **NEGATIVE**, dropping toward maximum negative. This voltage begins to charge the condenser again, but this time it's a **NEGATIVE** charge. Hence, the current curve is still on the **NEGATIVE** side of the zero axis, but is decreasing toward zero. Current will reach zero at instant  $d$ , when the voltage is momentarily stationary at maximum **NEGATIVE** before starting to decrease to zero. At instant  $d$ , voltage begins to drop, so the condenser

starts feeding its **NEGATIVE** charge **BACK** into the circuit. Hence, the negative charge with its direction reversed, puts a **POSITIVE** current into the circuit. The current curve climbs to maximum positive at instant  $e$ .

You will see that current wave  $I$  **LEADS** voltage wave  $E$  by  $90^\circ$ . You can now draw the vector diagram, shown in figure 51.

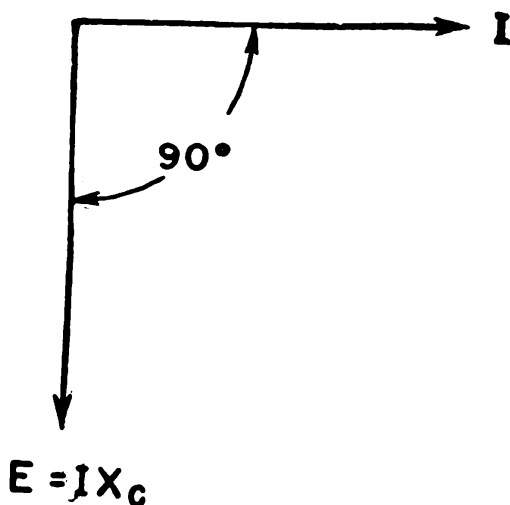


Figure 51.—Vector diagram for capacitance.

Alternating current does not actually **FLOW** through the insulation of the condenser, of course, but the condenser is alternately charged and discharged, making a quantity of electricity flow into the positive plate and then out again, and so on. This alternating charging and discharging of the condenser plates makes up the a.c. The greater the number of alternations per second, the more current that is charged on and discharged each second by the condenser, and the greater is the flow of current. Therefore, the current across a condenser is proportional to the frequency of the voltage.

And so, we can write a formula—

$$I = E (2\pi f C)$$

where  $I$  is effective current,  $E$  is effective voltage,  $f$  is the frequency, and  $C$  is the capacitance of the condenser in FARADS.

And it's perfectly good mathematics to invert that equation and make—

$$I = E (2\pi f C) = \frac{E}{\frac{1}{2\pi f C}}$$

The fraction,  $\frac{1}{2\pi f C}$  is the CAPACITIVE REACTANCE or inverse capacitance of a circuit and is expressed by—

$$\frac{1}{2\pi f C} = X_c, \text{ in OHMS}$$

Then—

$$I = \frac{E}{X_c} \text{ and } E = I X_c$$

### RESISTANCE AND INDUCTANCE IN A-C CIRCUIT

In figure 52, you have the diagram for a circuit containing a resistance  $R$  and an inductive reactance

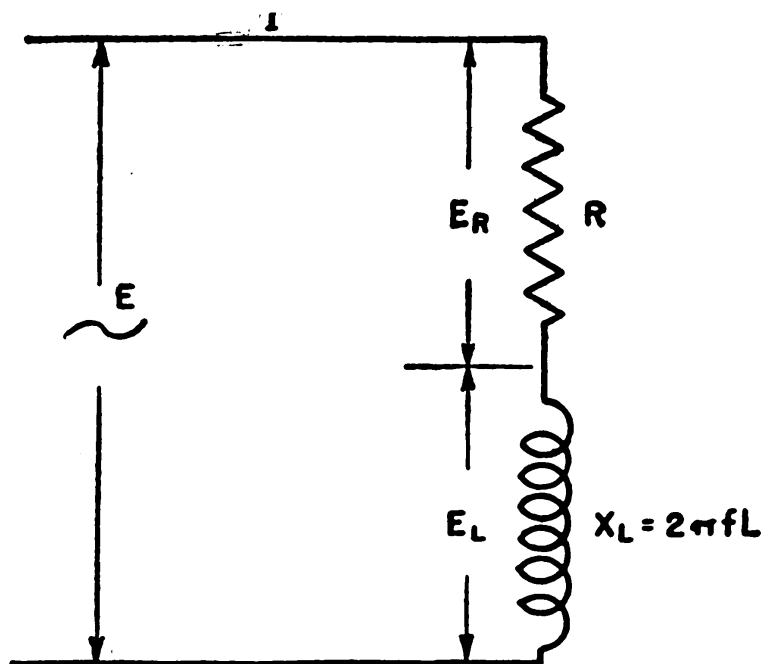


Figure 52.—Resistance and inductance in series.



$X_L$ . An a-c voltage of  $E$  volts and  $f$  cycles is impressed on the circuit, and  $I$  amperes flow. You want to find out all about the circuit.

Draw a vector diagram. Lay off  $I$  to a convenient scale and in a convenient position. Next lay off the voltage through the resistance. Remember you found out that the voltage,  $E_R$ , through a resistance is IN PHASE with the current. Then make your vector  $E_R$  lie along vector  $I$ , and to scale, as in figure 53.

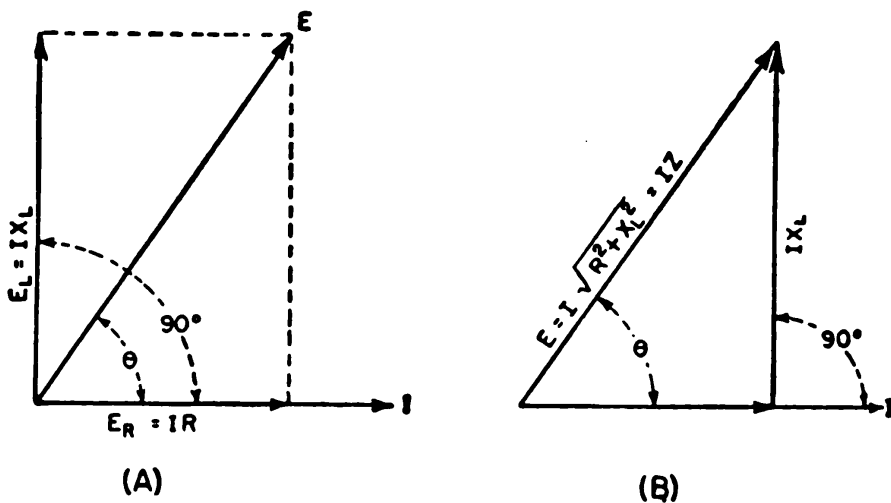


Figure 53.—Vector diagram for circuit in figure 52.

You also will remember reading that the voltage,  $E_L$ , through an inductance is  $90^\circ$  out of phase, leading, with current through the inductance. So lay off  $E_L$  leading  $I$  by  $90^\circ$ , and to scale. Now if you construct your parallelogram around  $E_R$  and  $E_L$ , you'll discover the total voltage through the resistance and the inductance. The resultant vector,  $E$ , in figure 53B, gives you the value and direction of  $E$ .

### RUN THROUGH THIS PROBLEM

You have a 110 volt, 60-cycle voltage on a circuit that includes a 100-ohm resistance and a 0.1-henry

inductance. You want to know: (a) Impedance of the circuit; (b) value of current flow; (c) voltage across resistance; (d) voltage across inductance; (e) angle of lead of voltage and current. Draw the vector diagram.

$$\begin{aligned}\text{First, (a) } Z &= \sqrt{R^2 + (2\pi fL)^2} \\ &= \sqrt{100^2 + (2\pi \times 60 \times 0.1)^2} \\ &= \sqrt{10,000 + 1,420} = \sqrt{11,420} \\ &= 107 \text{ ohms (ans.)}\end{aligned}$$

$$\text{Next, (b) } I = \frac{E}{Z} = \frac{110}{107} = 1.03 \text{ amps. (ans.)}$$

$$\text{Then, (c) } E_R = IR = 1.03 \times 100 = 103 \text{ v. (ans.)}$$

$$\begin{aligned}\text{And, (d) } E_L &= IX_L = I(2\pi fL) \\ &= 1.03 (2\pi \times 60 \times 0.1) = 38.8 \text{ v. (ans.)}\end{aligned}$$

$$\begin{aligned}\text{So, (e) } \tan \theta &= \frac{X_L}{R} \times \frac{2\pi \times 60 \times 0.1}{100} = 0.376 \\ \text{and } \theta &= 20.6^\circ \text{ (ans.)}\end{aligned}$$

And the vector diagram is in figure 54.

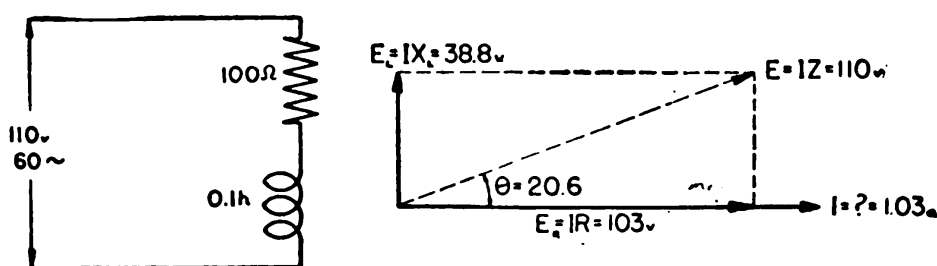


Figure 54.—Diagram for problem.

## POWER

No power is used up by the pure inductance in a circuit. Here's why. As the current increases from zero to a maximum value, it stores up energy in the

magnetic field of the inductance. Then as the current decreases from maximum to zero, all this stored energy is released back into the circuit.

ALL the power used up in a circuit is expended in resistance so that—

$$P = I (IR) = I^2 R$$

and since from figure 54, by trigonometry you find that you can substitute, and get—

$$IR = E \cos \theta$$

Earlier you saw that  $\cos \theta$  is the POWER FACTOR of a circuit, so the *P.F.* is equal to TRUE POWER,  $P$ , divided by APPARENT POWER,  $EI$ . Then—

$$P.F. = \frac{P}{EI}$$

#### A POWER PROBLEM

In that problem on page 76, find out how much power is consumed and what factor the circuit has.

$$P = I^2 R = 1.03^2 \times 100 = 1.06 \times 100 = 106 \text{ watts.}$$

and—

$$P.F. = \frac{106}{110 \times 1.03} = 0.935 = 93\frac{1}{2}\% \text{ P.F.}$$

You can also find the *P.F.* by using

$$P.F. = \cos \theta = \cos 20.6^\circ = 0.936 = 93\frac{1}{2}\%$$

#### RESISTANCE AND CAPACITANCE IN A-C CIRCUIT

In figure 55A, you have the diagram of a circuit containing both resistance,  $R$ , and capacitance,  $C$ , in series. An a-c voltage is connected across this circuit, and an alternating current,  $I$ , flows in the lines. What are the relations between  $E$ ,  $I$ ,  $R$ , and  $X_c$ ?

Look at the vector diagram for this circuit in figure 55B. It's a triangle vector diagram for a

change, not a parallelogram. Current,  $I$ , flows through the resistance and the condenser. So you lay off  $I$  as a vector arrow to a convenient length, and horizontally. You remember that the voltage,  $E_R$ , through a resistor is IN PHASE with the current. So you lay off  $E_R = IR$  along the vector  $I$ .

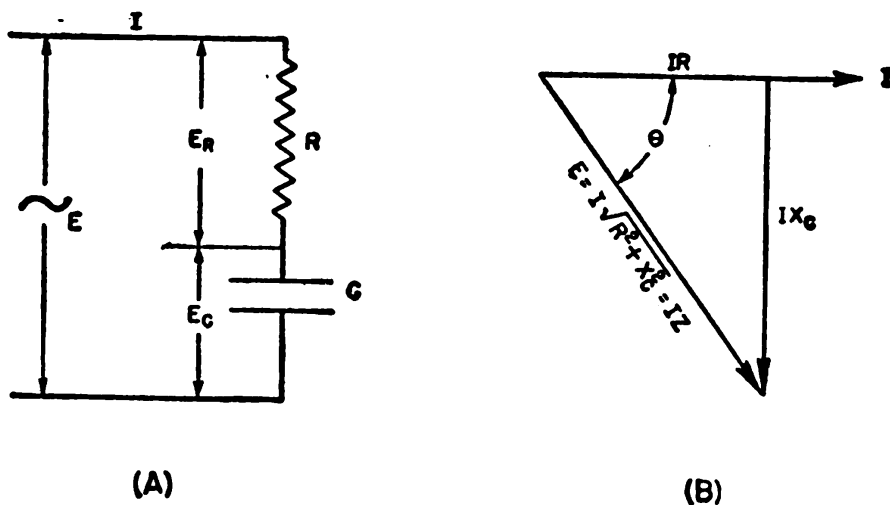


Figure 55.—Resistance and capacitance in series.

Now you come to the voltage,  $E_C$ , through the condenser. You've just learned that  $E_C$  must LAG the current through the condenser by  $90^\circ$ , so you lay off a vector  $90^\circ$  BEHIND  $IR$ , and measure off  $E_C = IX_C$  along it. Next draw the third side of the vector triangle, which gives you the value and direction of  $E$ . Because it is the hypotenuse of a right triangle—

$$E = \sqrt{(IR)^2 + (IX_C)^2}$$

$$= I\sqrt{R^2 + X_C^2}$$

Let  $\sqrt{R^2 + X_C^2}$  be represented by  $Z$ , the impedance of the circuit. Then—

$$E = IZ.$$

Or if you want the value of current,—

$$I = \frac{E}{Z}$$

Next, you can find the power used in the circuit. Since the capacitive reactance takes zero power, all the power is used by the resistance. Thus,—

$$P = I^2 R = I(IR)$$

Now you can find the angle of lag,  $\theta$ , by this formula—

$$\cos \theta = \frac{IR}{E} \text{ or } E \cos \theta = IR$$

Then substituting,

$$P = I(E \cos \theta) = EI \cos \theta$$

Recognize that formula? It's the same formula that you had on page 78 for power in a circuit containing inductance and resistance.

To find angle  $\theta$ , you use this formula—

$$\tan \theta = \frac{IX_c}{IR} = \frac{X_c}{R}$$

Then—

$$P.F. = \frac{R}{Z} = \cos \theta$$

#### A PROBLEM WILL EXPLAIN

You have a  $25\mu\text{f.}$  condenser and a 90-ohm resistance in series in a 110-volt, 60-cycle line. What is: (a) Impedance of the circuit; (b) current in circuit; (c) voltage across the resistance; (d) voltage across the condenser; (e) phase angle of voltage and current; (f) power; (g) power factor?

First,  $C = 25\mu\text{f.} = 0.000025 \text{ farad.}$

$$\begin{aligned} \text{Then, (a) } Z &= \sqrt{R^2 + X^2}, \text{ where } X_c = \frac{1}{2\pi f C} \\ &= \frac{1}{2\pi \times 60 \times 0.000025} = 106 \text{ ohms} \end{aligned}$$

$$\text{So } Z = \sqrt{90^2 + 106^2} = 139 \text{ ohms. (ans.)}$$

Next, (b),  $I = \frac{E}{Z} = \frac{110}{139} = 0.791$  amp. (ans.)

And, (c),  $E_R = IR = 0.791 \times 90 = 71.3$  volts (ans.)

And, (d),  $E_C = IX_C = 0.791 \times 106 = 84$  volts (ans.)

So (e),  $\tan \theta = \frac{X_C}{R} = \frac{106}{90} = 1.75 = \tan 60.3^\circ$

Then (f),  $P = I^2 R = (0.791)^2 \times 90 = 56.25$  watts (ans.)

Finally (g),  $P.F. = \frac{R}{Z} = \frac{90}{139} = 0.647$  (ans.)

### RESISTANCE, CAPACITANCE, AND INDUCTANCE IN CIRCUIT

And now we come to a REAL circuit—an a-c circuit with resistance  $R$ , capacitance  $X_C$ , and inductance  $X_L$ , all in series, and shown in figure 56. You put a voltage  $E$  of frequency  $f$  across this circuit, and current  $I$  flows. Next, find out how  $E$ ,  $I$ ,  $R$ , and  $X_C$  fit together in the circuit.

This is a series circuit, therefore current  $I$  is the

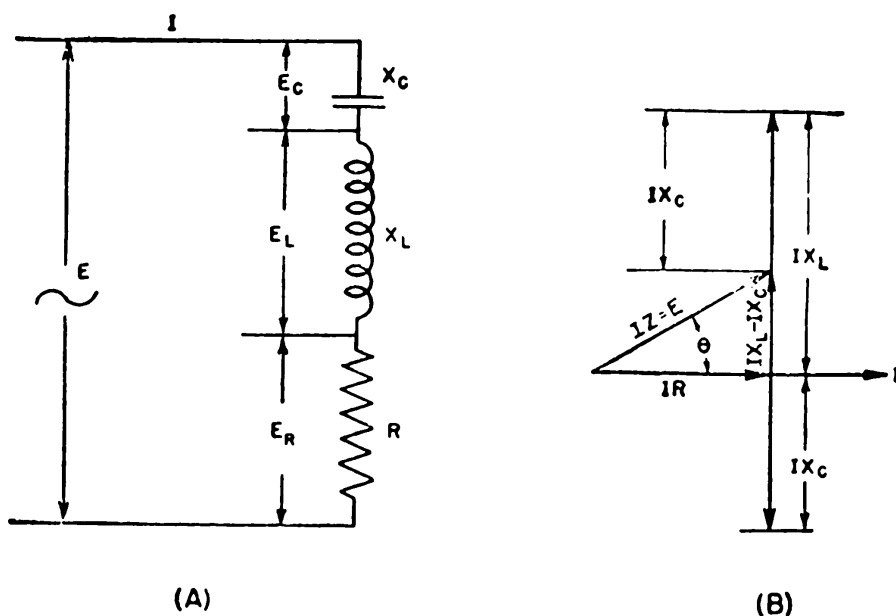


Figure 56.—Circuit containing resistance, capacitance, and inductance.

same throughout the circuit. You can start constructing the vector diagram in figure 56 by laying off the arrow for  $I$  horizontally. The voltage  $E_R$  through the resistance is IN PHASE with current  $I$ , and is equal to  $IR$ , since  $E_R = IR$ . So you can lay off  $IR$  to scale along vector  $I$ .

Voltage  $E_L$  through the inductance LEADS the current  $I$  by  $90^\circ$  so the vector for  $E_L = IX_L$  is laid off at right angles to  $I$ , and to scale. Voltage  $E_C$  through the capacitance LAGS current by  $90^\circ$ , and  $E_C = IX_C$ . You lay off the vector for  $IX_C$  at right angles, lagging  $I$ , and to scale.

Now you can see that  $E_L$  and  $E_C$  oppose each other. Also, since you've drawn your vectors to scale, you can readily see that  $IX_L$  is greater than  $IX_C$ . Now you can subtract  $IX_C$  directly from  $IX_L$ , as shown in the upper half of the vector diagram of figure 56.

You can now determine the line voltage  $E$  by a vector addition of the three voltages— $IX_L$ ,  $IX_C$ , and  $IR$ . This line voltage will be the hypotenuse of a right triangle, the other two sides of which are  $IR$  and  $(IX_L - IX_C)$ . By drawing this hypotenuse, you get vector  $E$ .

You now see that—

$$E = \sqrt{(IR)^2 + (IX_L - IX_C)^2}$$

since the hypotenuse of a right triangle is the square root of the sum of the square of the other two sides.

Then—

$$E = I\sqrt{R^2 + (X_L - X_C)^2}$$

and

$$I = \frac{E}{\sqrt{R^2 + (X_L - X_C)^2}}$$

Let—

$$R^2 + (X_L - X_C)^2 = Z$$

so

$$I = \frac{E}{Z} \text{ or } E = IZ$$

is the equation for a series a-c circuit which is STEADY at a voltage and a current.

You can find the PHASE ANGLE  $\theta$  by

$$\tan \theta = \frac{X_L - X_C}{R}$$

If  $X_L$  is greater than  $X_C$ ,  $\tan \theta$  is POSITIVE, angle  $\theta$  is positive, and  $I$  LAGS  $E$ , as in figure 56. But if  $X_L$  is LESS than  $X_C$ ,  $\tan \theta$  is NEGATIVE, angle  $\theta$  is negative, and  $I$  LEADS  $E$ .

The power factor is

$$\cos \theta = \frac{R}{Z}$$

#### PERHAPS A PROBLEM WILL HELP—

You have a circuit, shown in figure 57, with a 30-ohm resistance, a  $20\mu\text{f}$ . capacitance, and a 0.25-henry inductance, all in series. Voltage across the circuit is 110 volts, 60 cycles.

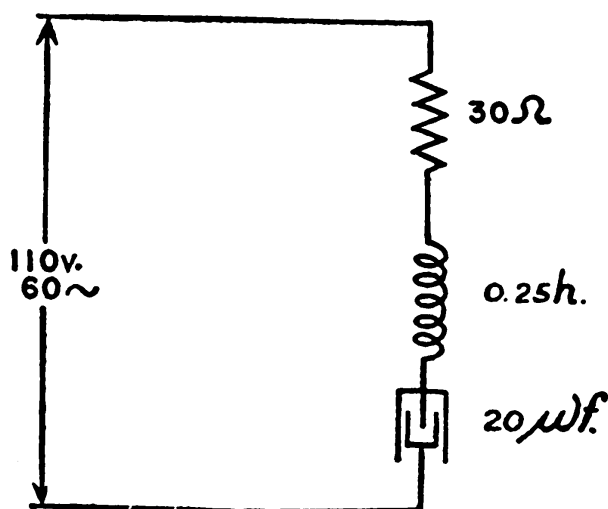


Figure 57.—Circuit containing resistance, inductance, and capacitance.

Find out the following about this circuit: (a) Impedance; (b) Current in the circuit; (c) Voltage across the resistance; (d) Voltage across the induc-



tance; (e) Voltage across the capacitance; (f) Power consumed by the circuit; (g) Phase angle; (h) Power factor; (i) Vector diagram.

First, find  $X_c$  and  $X_L$ —

$$\begin{aligned} X_c &= \frac{1}{2\pi fC} = \frac{1}{2\pi 60 \times 20\mu} = \frac{1}{2\pi 60 \times 0.000020} \\ &= \frac{1}{0.00753} = 133 \text{ ohms} \end{aligned}$$

$$X_L = 2\pi fL = 2\pi 60 \times 0.25 = 94.1 \text{ ohms}$$

$$\begin{aligned} \text{Now, (a), } Z &= \sqrt{R^2 + (X_L - X_c)^2} \\ &= \sqrt{30^2 + (94.1 - 133)^2} \\ &= \sqrt{30^2 + (-38.9)^2} = \sqrt{900 + 1510} \\ &= \sqrt{2410} = 49.1 \text{ ohms (ans.)} \end{aligned}$$

$$\text{And, (b) } I = \frac{E}{Z} = \frac{110}{49.1} = 2.24 \text{ amps. (ans.)}$$

$$\text{Next, (c) } E_R = IR = 2.24 \times 30 = 67.3 \text{ volts (ans.)}$$

$$\begin{aligned} \text{Then, (d) } E_L &= IX_L = 2.24 \times 94.1 \\ &= 211 \text{ volts (ans.)} \end{aligned}$$

$$\text{And, (e) } E_c = IX_c = 2.24 \times 133 = 298 \text{ volts (ans.)}$$

$$\begin{aligned} \text{So, (f) } P &= I^2 R = (2.24)^2 \times 30 \\ &= 151.5 \text{ watts (ans.)} \end{aligned}$$

$$\begin{aligned} \text{Next, (g) } \tan \theta &= \frac{X_L - X_c}{R} = \frac{94.1 - 133}{30} \\ &= \frac{-38.9}{30} = -1.295 \end{aligned}$$

$$\text{and } \theta = -37^\circ 40' \text{ (ans.)}$$

Since  $\theta$  is a MINUS angle, the current LEADS the voltage.

$$\begin{aligned}
 \text{Finally, } (h) \cos \theta &= \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}} \\
 &= \frac{30}{\sqrt{(30)^2 + (94.1 - 133)^2}} \\
 &= \frac{30}{\sqrt{(30)^2 + (-38.9)^2}} \\
 &= \frac{30}{\sqrt{900 + 1510}} \\
 &= \frac{30}{\sqrt{2410}} \\
 &= \frac{30}{49.1} = 0.61
 \end{aligned}$$

So  $P.F. = \cos \theta = 0.61 = 61\%$

(i) Vector diagram for this circuit is in figure 58. Notice that the voltage  $E_C$  across the capacitance is much larger than the line voltage  $E$ . You couldn't have this condition in a d-c circuit, since the voltage across any part of the d-c circuit cannot be greater than the line voltage.

However, this condition is perfectly normal for an a-c circuit, since the capacitance voltage  $E_C$  and the inductance voltage  $E_L$  are in direct opposition to each other. Both may be large, but their DIFFERENCE must not exceed line voltage.

### RESONANCE IN A SERIES CIRCUIT

You'll remember that the general formula for current through a circuit is

$$I = \frac{E}{\sqrt{R^2 + (2\pi fL - \frac{1}{2\pi fC})^2}}$$

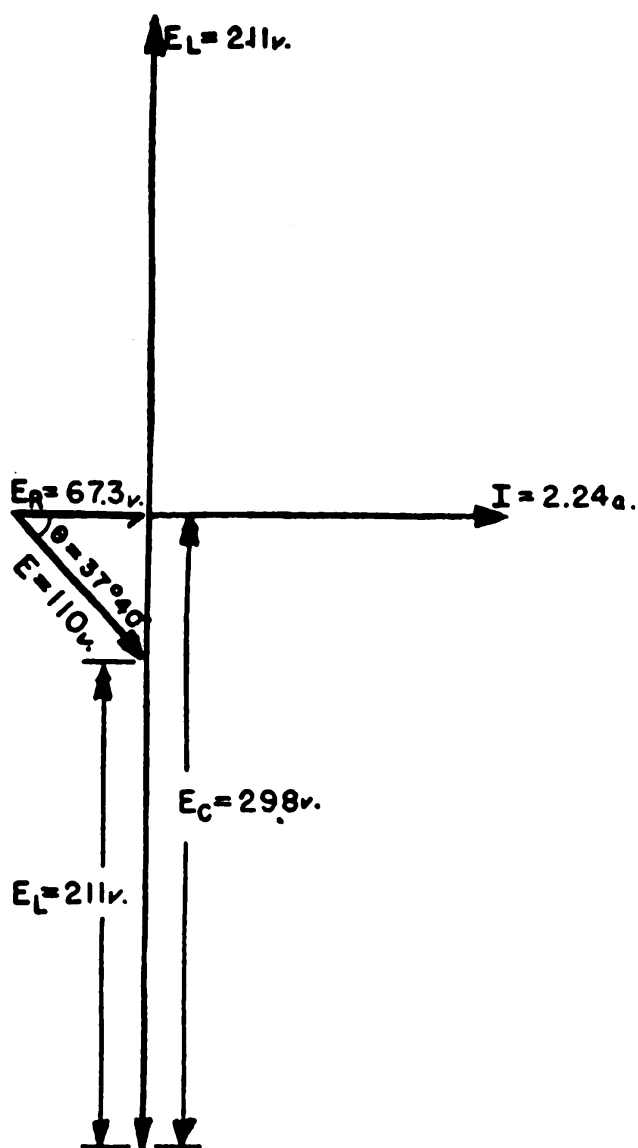


Figure 58.—Vector diagram of circuit containing inductance, resistance, and capacitance.

If the values of voltage  $E$  and resistance  $R$  are fixed, you'll find that the current through the circuit will be maximum when the unshaded portion of this equation, in figure 59, is equal to zero.

Thus, when  $(2\pi fL - \frac{1}{2\pi fC})$  is equal to zero, this equation becomes—

$$I = \frac{E}{\sqrt{R^2 + 0}} = \frac{E}{R}$$

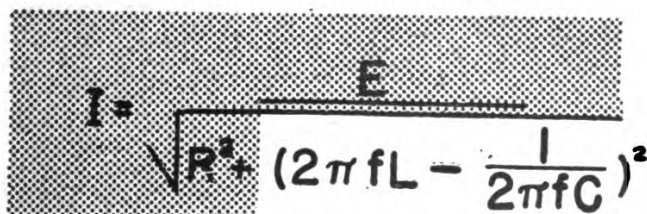
which is OHM'S LAW. Then, under these conditions,

$$2\pi fL = \frac{1}{2\pi fC}$$

Multiply each side by  $I$ , and

$$2\pi fLI = \frac{I}{2\pi fC}$$

so that voltage across the inductance is now equal to voltage across the capacitance. Since voltage across the inductance LEADS the current by  $90^\circ$ , and voltage



$$I = \frac{E}{\sqrt{R^2 + (2\pi fL - \frac{1}{2\pi fC})^2}}$$

Figure 59.

across the CAPACITANCE lags the current by  $90^\circ$ , the two voltages,  $2\pi fLI$  and  $\frac{I}{2\pi fC}$  are  $180^\circ$  apart, or directly opposite each other. Look at the vector diagram in figure 60. See how the vector for inductance voltage is equal and opposite to capacitance voltage under these conditions.

When these conditions exist, the series circuit is in RESONANCE, and the current  $I$  is IN PHASE with the line voltage  $E$ . Power  $P$  is equal to  $EI$ .

You can now find the FREQUENCY at which the circuit is RESONANT by making—

$$2\pi fL - \frac{1}{2\pi fC} = 0$$

when  $L$  and  $C$  have fixed values.

Then

$$f = \frac{1}{2\pi \sqrt{LC}}$$

which is also called the NATURAL FREQUENCY of the

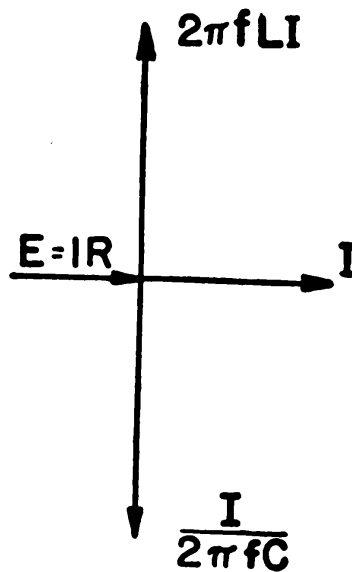


Figure 60.—Vector diagram.

circuit. This is the frequency at which the circuit would oscillate if placed in an oscillator circuit.

REMEMBER—the CURRENT IS MAXIMUM WHEN the SERIES CIRCUIT IS IN RESONANCE.

### RESONANCE CHARACTERISTICS OF SERIES CIRCUIT

If the frequency  $f$  in a circuit is fixed at a certain number of cycles, you can get numberless combinations of inductance and capacitance to give the circuit resonance. As long as  $LC$  remains constant, you can vary the values of  $L$  and  $C$  to get hundreds

of combinations. To explain simply, suppose you want

$$LC = 12$$

You can get 12 by multiplying  $4 \times 3$ ,  $6 \times 2$ ,  $1 \times 12$ ,  $0.5 \times 24$ ,  $0.1 \times 120$ , and so on, through many combinations.

However, the characteristics of the current vary according to the relation of the inductance  $L$  to capacitance  $C$ . Look at figure 61 to see what is meant.

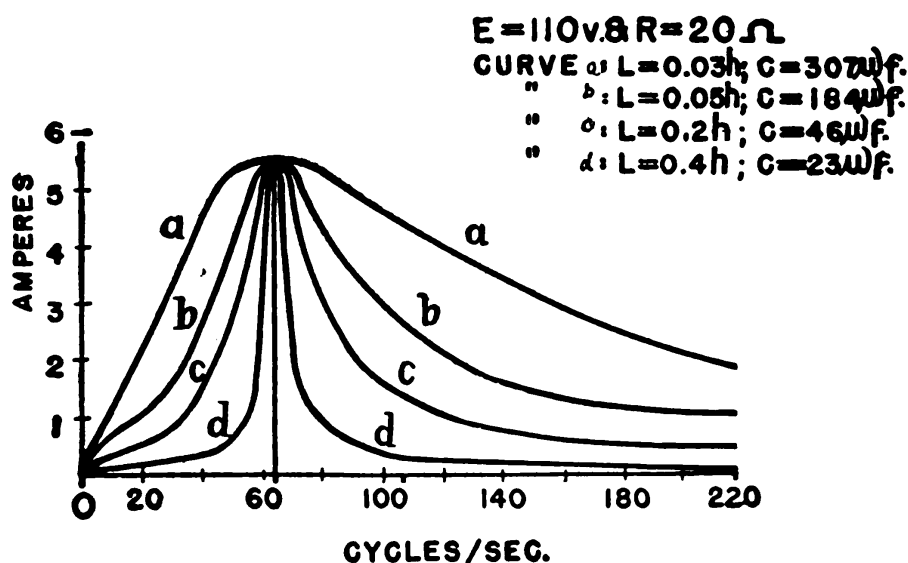


Figure 61.—Resonance curves.

The circuit has a voltage  $E$  of 110 volts across it, the resistance is 20 ohms, and you tune the circuit first to 60 cycles frequency by making the inductance  $L = 0.03$  henry and the capacitance  $C = 307 \mu\text{f.}$  or microfarads. You see the variation of current  $I$  with frequency variations charted by curve  $a$ . The current at zero frequency is zero amperes, since a current of zero frequency is a direct current, and the condenser gives an open circuit on d.c.

You've adjusted  $L$  and  $C$  originally to make the current a maximum when the frequency is 60 cycles. You can now see from the values of  $L$  and  $C$  for the four curves in figure 61 that as inductance  $L$  is increased and capacitance  $C$  is decreased to keep  $LC$  constant, the tuning curve becomes sharper. In other words, a very small change in frequency on either side makes a large decrease in current, until curve  $d$  is quite sharp.

This is the method by which radio and telephone circuits are tuned sharp. Resonance is highly important in communications circuits, in order that the receiver will pick up only a certain tuned frequency, and will shut out all other neighboring frequencies.

## PARALLEL CIRCUITS

Actually, you'll run into many more PARALLEL circuits in electrical systems than you will find SERIES circuits, since distribution and transmission of a.c. is generally handled by parallel circuits.

In solving these parallel circuits, you'll find vectors of great help, since in finding the current through several parallel loads, you find the current through each load, and then add these loads by vectors to obtain the resultant current.

## A PROBLEM

Probably a problem will help you see the solution of parallel circuits—

You have a 12-ohm resistance, a 10-ohm inductive reactance, and an 18-ohm capacitive reactance in parallel across a 110-volt 60 cycle line, as at the top of figure 62. Find: (a) Total current; (b) Circuit power factor; and (c) Power.

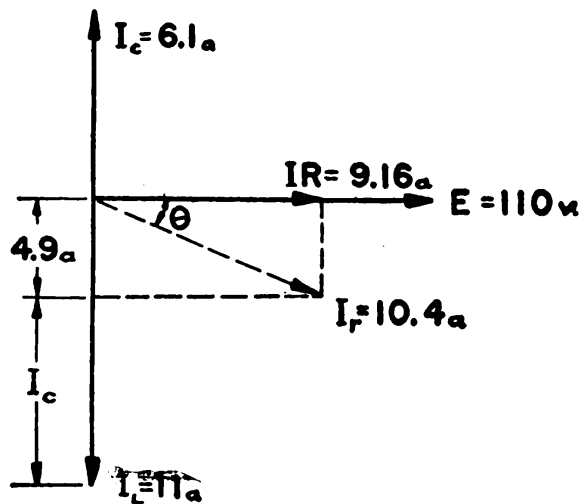
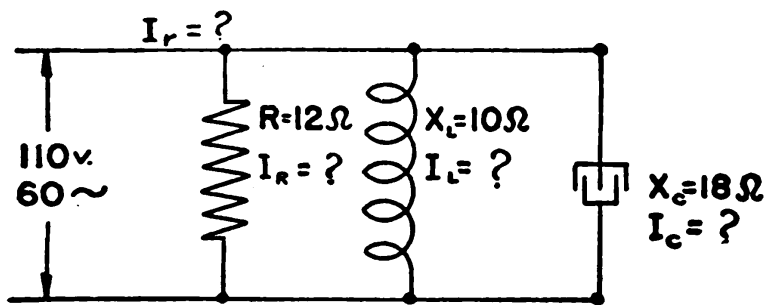


Figure 62.—Circuit diagram and vector diagram.

First, get the current through each leg of the circuit.

$$I_R = \frac{E}{R} = \frac{110}{12} = 9.16 \text{ a.}$$

$$I_L = \frac{E}{X_L} = \frac{110}{10} = 11 \text{ a.}$$

$$I_C = \frac{E}{X_C} = \frac{110}{18} = 6.1 \text{ a.}$$



Next, draw the vector diagram, bottom of figure 62. Lay off  $E = 110$  v. as a horizontal vector, since the voltage is the same throughout the circuit.

Then, since current through a resistance is IN PHASE with voltage, you can lay off  $I_R$  to a scale along vector  $E$ .

Now, remembering that current through an inductance LAGS voltage, lay off  $I_L$  to scale and  $90^\circ$  BEHIND  $I_R$ . And since current through a capacitance LEADS voltage by  $90^\circ$ , lay off  $I_C$  to scale  $90^\circ$  AHEAD of  $I_R$ .

Since  $I_L$  and  $I_C$  are in direct opposition, ADD them by vectors, and you get  $I_L + [(-I_C)]$  or  $(11-6.1) = 4.9$  a., LAGGING.

$$\begin{aligned}\text{Then, (a) } I_T &= \sqrt{(9.16)^2 + (4.9)^2} \\ &= \sqrt{24 + 83.9} = \sqrt{107.9} \\ &= 10.4 \text{ a. (ans.)}\end{aligned}$$

$$\begin{aligned}\text{And, (b) } P.F. &= \cos \theta = \frac{I_R}{I_T} = \frac{9.16}{10.4} = 0.882 \\ &= 88.2\% \text{ (ans.)}\end{aligned}$$

$$\text{So, (c) } P = EI_R = 110(9.16) = 1,008 \text{ watts (ans.)}$$

## RESONANCE IN A PARALLEL CIRCUIT

A parallel circuit is in resonance when the resultant current is in phase with the line voltage. In this case, inductance current and capacitance current must be equal. Since they oppose each other, they will cancel, leaving only resistance current in the circuit. Look at figure 63. Figure 63A is the circuit diagram, figure 63B is the sine curve diagram and shows the relationship between voltage  $E$ , resistance

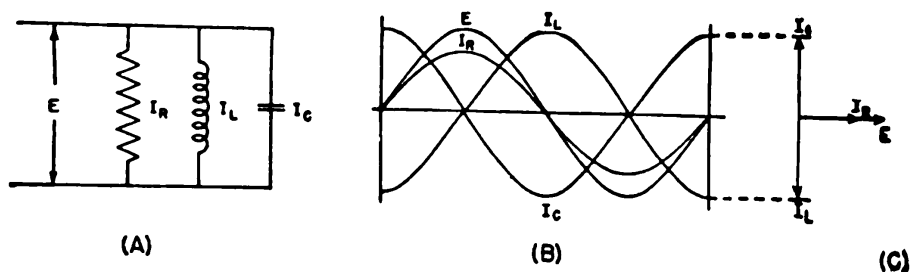


Figure 63.—Resonance in a parallel circuit.

current  $I_R$ , inductance current  $I_L$ , and capacitance current  $I_C$ . From figure 63C, the vector diagram of the currents and voltage, you see that  $I_C$  leads  $I_L$  by  $180^\circ$ .  $I_C$  is equal to  $I_L$ , and the two voltages cancel each other.

You will notice that  $I_T$ , or total current in the PARALLEL circuit, is a MINIMUM when the circuit is in resonance. But in a SERIES circuit,  $I_T$  is MAXIMUM when the circuit is in resonance. Here's why. In a PARALLEL circuit, inductance and capacitance CURRENTS are equal and opposite at the resonance point. But in a SERIES circuit, inductance and capacitance VOLTAGES are equal and opposite at the resonance point. Read this paragraph again to get the differences straight in your mind.

### ACTUAL CIRCUIT CONDITIONS

Up to now, you've been assuming that the inductance and capacitance circuits you're handling are perfect—no resistance, no current losses, and with inductance and capacitance currents exactly  $90^\circ$  away from their voltages. Actually, though, the wire in an inductance coil must have SOME resistance, and iron-core coils have core losses equivalent to resistance. You can't design impedance coils commercially that have a phase angle better than about  $87^\circ$ . And even the best condensers fall a little short of  $90^\circ$  phase angle.

As a result of these various losses and resistances

and angles short of  $90^\circ$ , you'll have to make slight adjustments in the actual problems you'll face in dealing with a.c. Probably a typical actual problem will show you what we mean.

### HERE'S THE PROBLEM—AND SOLUTION

An impedance coil and a resistance are in series in a circuit having 110 volts of 60-cycle a.c. across the lines. The current is 6 amps. By using a voltmeter, you've found that the voltage across the resistance is 65 volts, and the voltage across the impedance coil is 85. You want to know (a) Value of the resistance coil, (b) Circuit P.F. angle and P.F., (c) Impedance-coil P.F. angle and coil P.F., (d) Circuit Power, (e) Impedance-coil power, (f) Impedance-coil resistance, and (g) Impedance-coil reactance. Quite a lot, but easy to get.

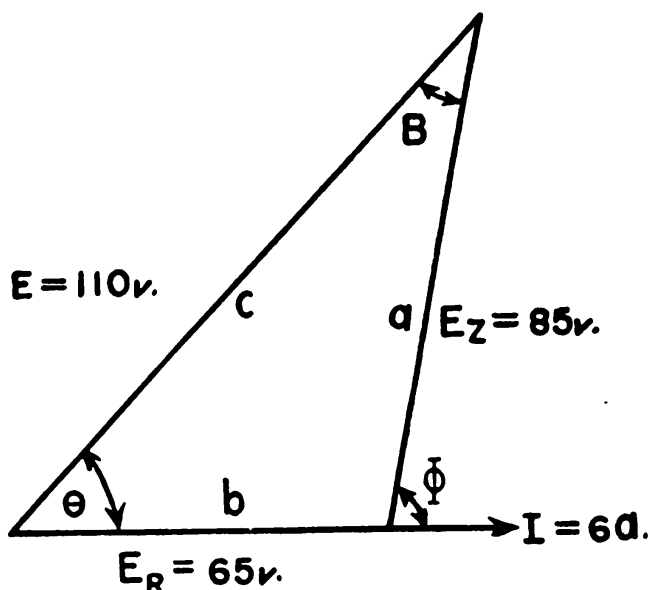


Figure 64.—Vector diagram for problem.

First, look at figure 64 for the diagram.

$$\text{Next, (a) } R = \frac{E_R}{I} = \frac{65}{6} = 10.82 \text{ ohms (ans.)}$$

Then, (b) By the law of cosines

$$\begin{aligned} \cos \theta &= \frac{b^2 + c^2 - a^2}{2bc} = \frac{65^2 + 110^2 - 85^2}{2(65 \times 110)} \\ &= \frac{4,225 + 12,100 - 7,225}{14,300} = \frac{9,100}{14,300} = 0.636 \text{ (ans.)} \\ \text{so } \theta &= 50.5^\circ \end{aligned}$$

And (c) By the law of sines,

$$\begin{aligned} \sin B &= \frac{b \sin \theta}{a} = \frac{65(0.7716)}{85} = 0.5910 \\ B &= 36.2^\circ \text{ (ans.)} \end{aligned}$$

$$\phi = \theta + B = 50.5 + 36.2 = 86.7^\circ \text{ (ans.)}$$

$$\cos \phi = \cos 86.7^\circ = 0.0576 \text{ (ans.)}$$

Next, (d)  $P = EI \cos \theta$

$$= 110 \times 6 \times 0.636 = 419 \text{ watts (ans.)}$$

So (e)  $P' = E_z' \times I \times \cos \phi$

$$= 85 \times 6 \times 0.0576 = 29.4 \text{ watts (ans.)}$$

$$\text{and } P_r = 65 \times 6 = 390 \text{ watts}$$

$$\text{So } P = P' + P_r = 29.4 + 390 = 419.4 \text{ watts (check)}$$

Then (f)  $I^2 R' = 29.4 \text{ watts}$

$$R' = \frac{29.4}{I^2} = \frac{29.4}{36} = 0.816 \text{ ohm. (ans.)}$$

$$\text{So (g) } E_x' = E_z' \sin \phi = 85(0.0576) = 4.89 \text{ v.}$$

$$\frac{4.89}{6} = 0.815 \text{ ohm reactance. (ans.)}$$

### THREE-PHASE ALTERNATORS

In the discussion of the simple a-c alternator, you used a single loop or several loops connected in

series. You needed only two leads to carry the current from the generator to the load. This type of a generator is known as a SINGLE-PHASE GENERATOR, since it generates only ONE current and voltage. A generator constructed so that THREE SEPARATE WINDINGS are used is more efficient. The three windings are spaced  $120^\circ$  apart around the armature.

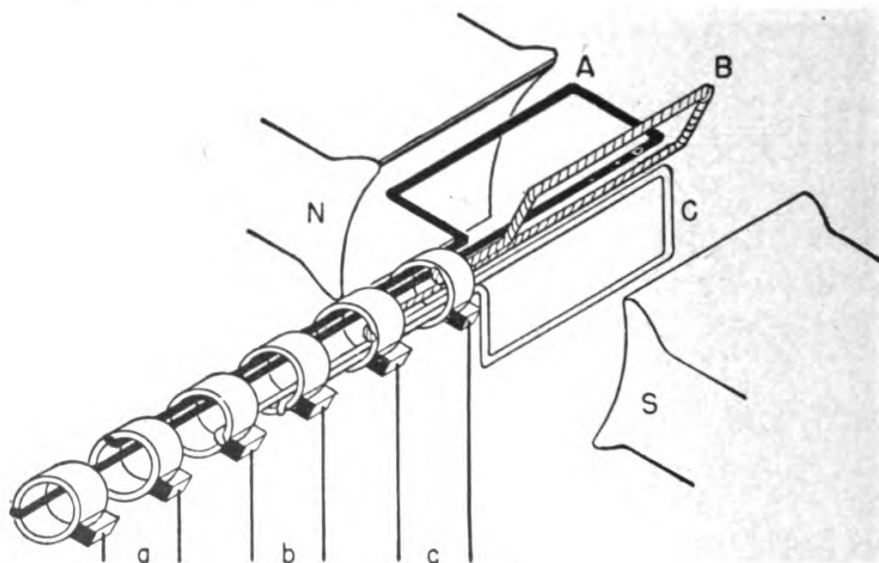


Figure 65.—Three-phase alternator.

You have three coils spaced  $120^\circ$  apart, rotating in a steady magnetic field, as shown in figure 65. As coil *A* passes under the north pole, a voltage will be induced. If the circuit is complete, a current will flow out at point *a*. After the armature has rotated  $120^\circ$ , coil *B* will occupy the same position as coil *A* in the diagram. Likewise, in this position, current will flow out at *b*. The same will be true for coil *C*. By using TWO slip rings for each coil, you can lead the current to the load through six wires. The result would be about the same as if you built three separate generators into one machine.

Figure 66 shows the voltage waves from the three coils. The curve for coil *A* starts its increase  $120^\circ$

BEFORE coil *B*. Likewise, the curve for coil *B* starts its increase  $120^\circ$  before coil *C*. The result is, there-

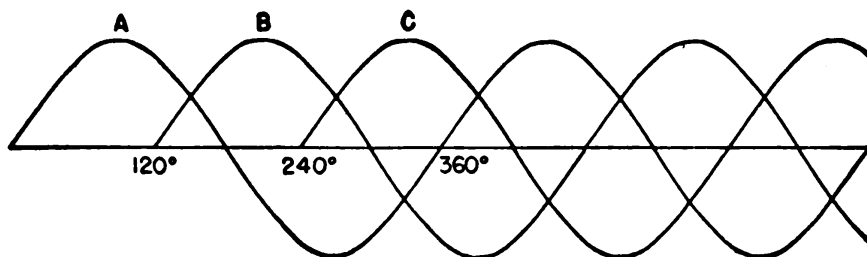


Figure 66.—Voltage curves for three-phase alternator.

fore, THREE SEPARATE VOLTAGES,  $120^\circ$  apart in phase-relation to each other.

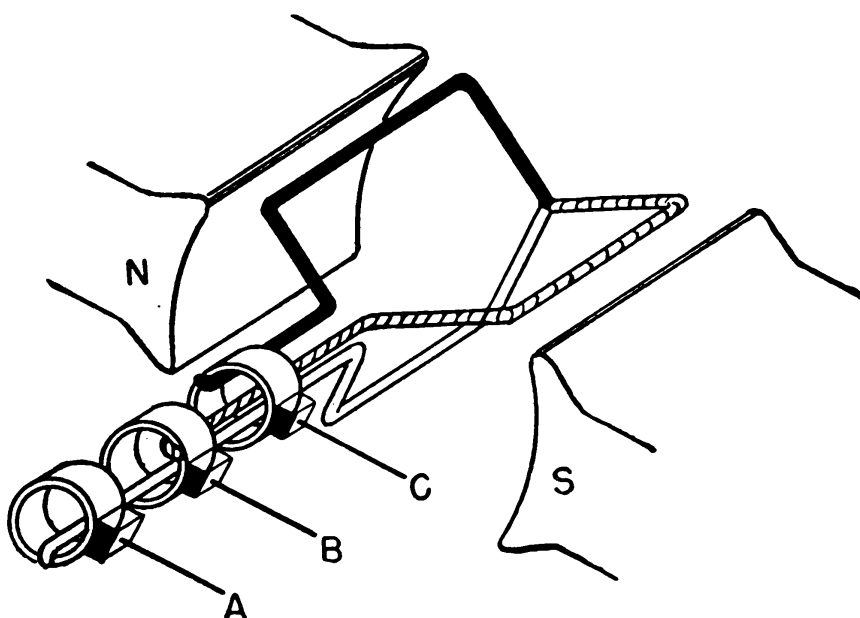


Figure 67.—Three-phase generator using three slip-rings.

Now connect the coils as shown in figure 67. You can do away with three wires and yet maintain your three-phase system. This is the way three-phase generators are usually connected. A schematic diagram is shown in figure 68. This type of connection is known as STAR, or WYE (*Y*) CONNECTION. In many

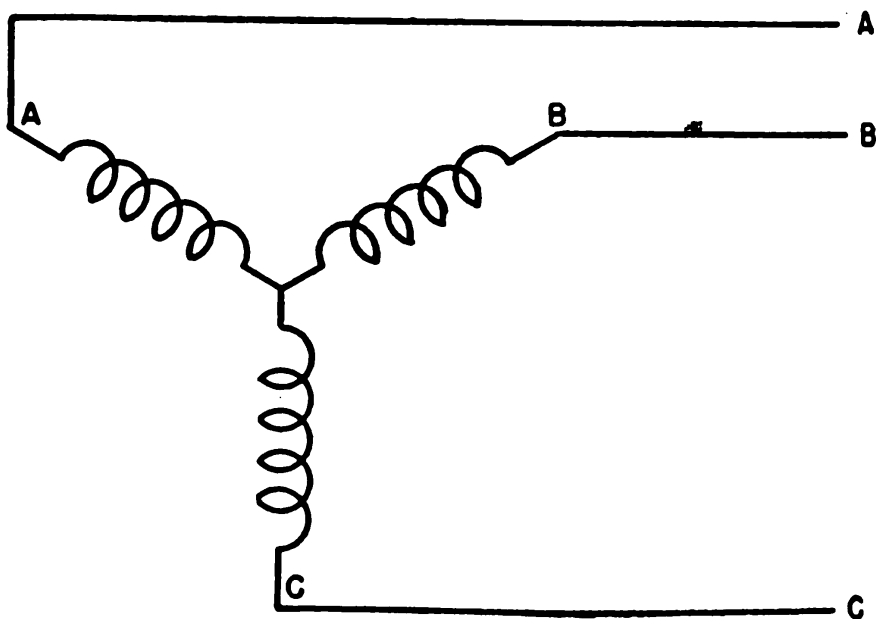


Figure 68.—Schematic of figure 67.

three-phase generators, the WINDINGS are placed on the frame or YOKE of the generator, and the FIELD is the ROTATING part. Thus, a positive connection can be made to the generator windings, and only two slip rings are needed to carry the current to the field poles.

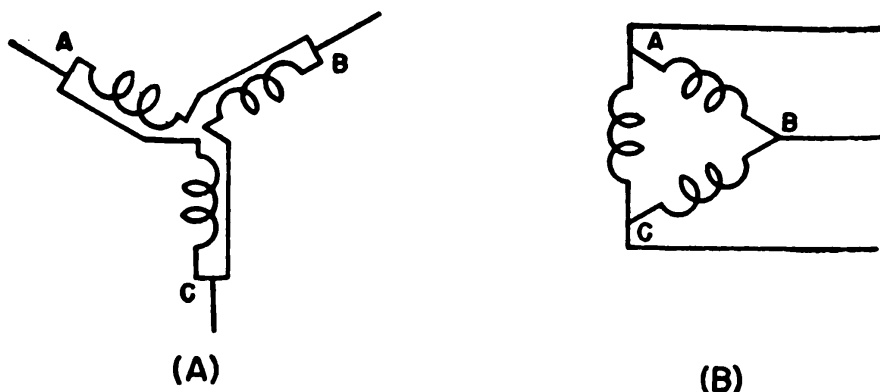


Figure 69.—Three-phase delta connection.

Another type of connection you will use in three-phase systems is the  $\Delta$ , or DELTA, connection shown in

figure 69. The same phase-difference exists in the delta connection as in the *Y* connection. Notice that the delta is similar to it in that the coils generate voltages in the same direction and magnitude.

In order to better understand the three-phase system, study its vector diagram. Figure 70 shows the schematic and vector diagram of a balanced *Y*-

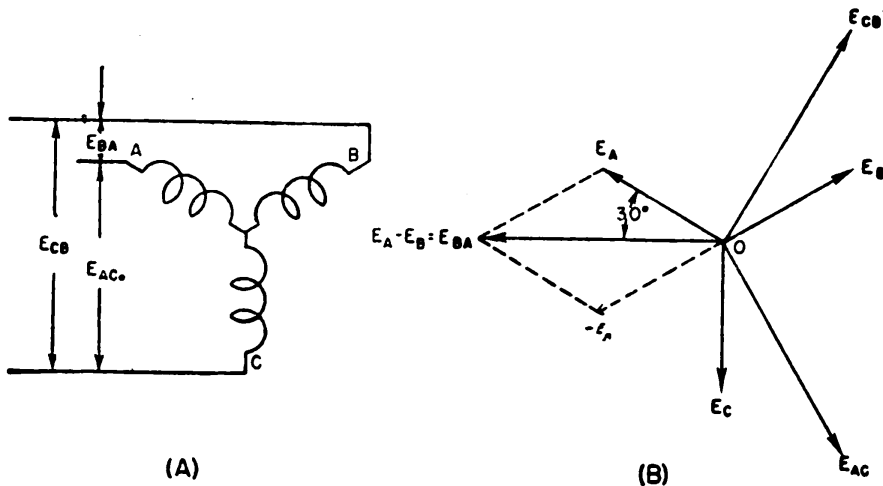


Figure 70.—Three-phase wye connection and vector diagram.

connected system. The individual phase voltages  $E_A$ ,  $E_B$ , and  $E_C$  act from the point  $O$  out in each direction. On the other half of the cycle they would act in the opposite direction, but for the purpose of discussion we will deal with INSTANTANEOUS values. The LINE VOLTAGE,  $E_{BA}$ , is the vector DIFFERENCE between phase voltages  $E_A$  and  $E_B$ . The value of  $E_{BA}$  equals  $2E_A \cos 30^\circ$  because the phase voltage  $E_A$  is  $30^\circ$  out of phase with the line voltage  $E_{BA}$ . For the same reason then, the line current at unity power factor will be  $30^\circ$  out of phase with the line voltage. The value of  $2 \cos 30^\circ = \sqrt{3}$ . Therefore,  $E_{BA} = \sqrt{3}E_A$ .

You see the vector diagram for a DELTA connection in figure 71. The voltage developed in each of the coils is shown by corresponding vectors. By extend-



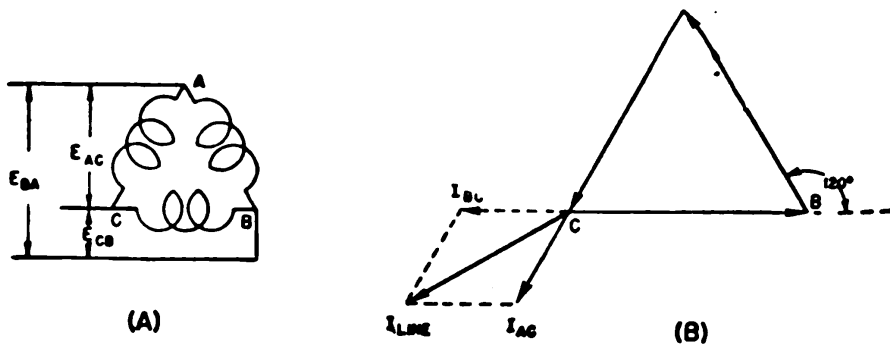


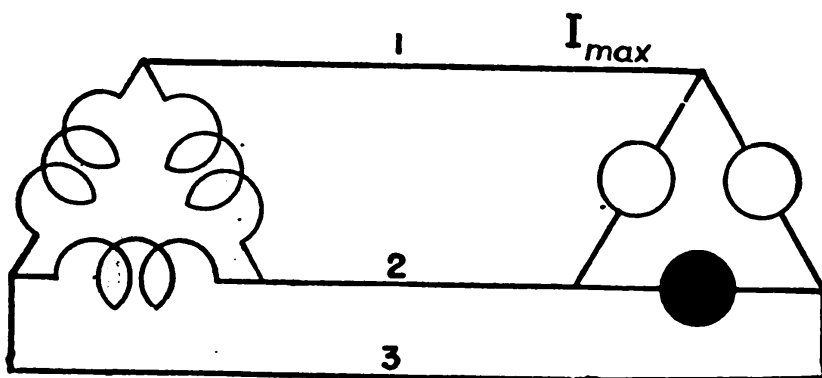
Figure 71.—Delta connection and vector diagram.

ing line  $E_{CB}$  you see that  $E_{OB}$  and  $E_{BA}$  are  $120^\circ$  out of phase. This is also true for the other voltages. But, the LINE voltage in this case equals the COIL voltage. Such was not true of the Y-connected system.

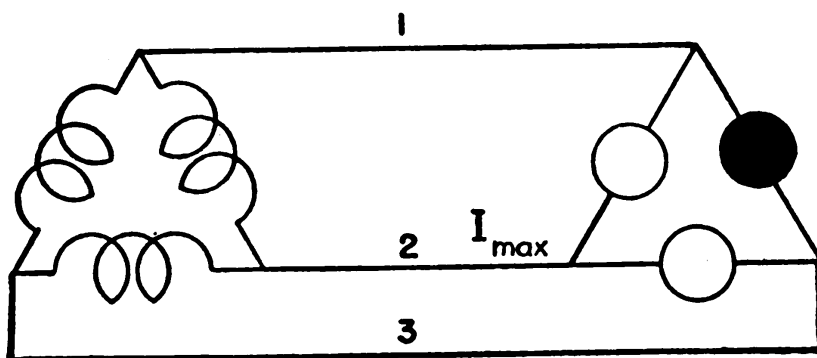
Next, consider the current flowing into the line at  $C$ . If the current produced by  $E_{AC}$  and the current produced by  $E_{CB}$  flow into the line, the current from  $E_{CB}$  must have a direction OPPOSITE to  $E_{CB}$  as shown by  $I_{BC}$ . When this current is combined with  $I_{AC}$ , the resultant line current is  $I_L$ . From this diagram it can be seen that this CURRENT,  $I_L$ , is  $30^\circ$  OUT OF PHASE with the PHASE VOLTAGE,  $E_{AC}$ . Therefore, the LINE CURRENT in a DELTA-connected system is equal to  $\sqrt{3}$  times the PHASE current.

$$I_L = \sqrt{3}I_{phase}$$

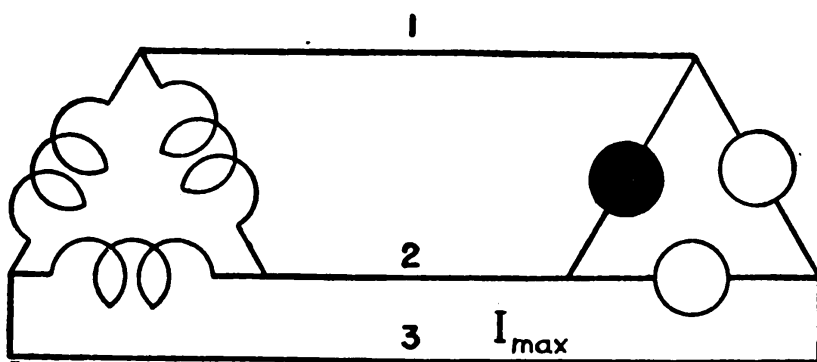
The three-phase cycle is shown in figure 72. A DELTA-connected system is connected to a delta of lamps. In  $A$ , the current in line 1 is a maximum and flows out through two lamps and returns through lines 2 and 3. One lamp does not burn because no voltage is applied to it. In  $B$ , the current is maximum through line 2 and returns through lines 1 and 3. This time the lamp between 1 and 2 is out. Of course, as with all incandescent lamps, the filaments do not have time to cool and do not actually go out during the time that no current flows through them.



(A)



(B)



(C)

Figure 72.—Three-phase sequence of current maximums.

## POWER IN A THREE-PHASE CIRCUIT

The CURRENT in phase  $OA$  is in phase with the VOLTAGE  $OA$  if the system is at UNITY power factor. See figure 73. This is also true for each of the other phases. Therefore, the TOTAL POWER is given by the formula  $P = 3E_{phase} I_{phase}$

where  $I_{phase} = I_{line}$

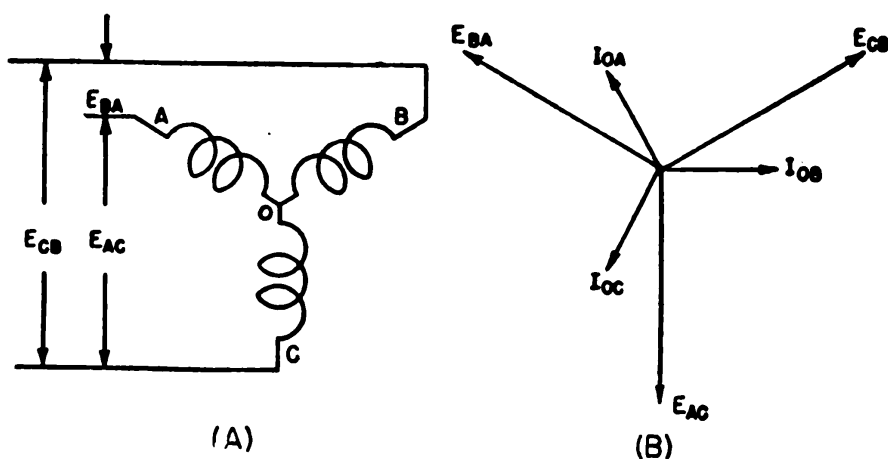


Figure 73.—Three-phase power.

However, the LINE VOLTAGE is equal to  $\sqrt{3}E_{phase}$ . Thus, if you substitute  $E_{line}$  for  $E_{phase}$ , the formula becomes

$$P = \frac{3 E_{line} I_{phase}}{\sqrt{3}} = \sqrt{3} E_{line} I_{line}$$

If the power factor is NOT UNITY, then the phase current will lag or lead the phase voltage by an angle  $\theta$ . Therefore, the TOTAL POWER formula in the line will become

$$P = 3 E_{phase} I_{phase} \cos \theta_{phase} \text{ and}$$

$$P = \sqrt{3} E_{line} I_{line} \cos \theta_{line}.$$

This is the general power formula for three-phase circuits. In the case of a delta-connected system, the

phase voltage and line voltage are the same, but the line current is  $\sqrt{3}$  times the phase current. Thus, the same formula holds true.

## TRANSFORMER CONNECTIONS FOR THREE-PHASE CIRCUITS

In most transformer connections for THREE-PHASE circuits, SINGLE-PHASE TRANSFORMERS are used. The PRIMARIES are connected in either Y or DELTA, and the SECONDARIES are connected in a similar manner.

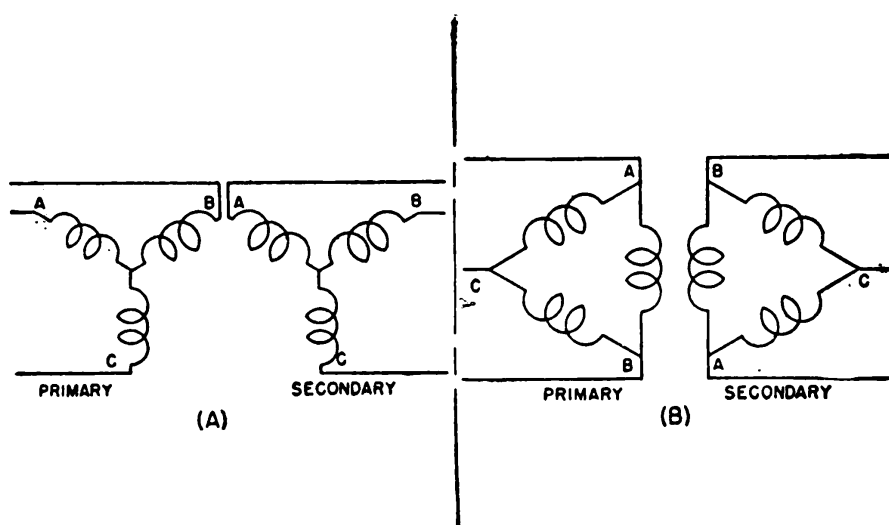


Figure 74.—Transformer connections.

Figure 74A and B, shows the transformer connections for Y-TO-Y and DELTA TO-DELTA systems. In this type of connection, the VOLTAGE ratio between primary and secondary is determined by the TURNS ratio. That is, if 100 volts between lines on the primary is applied and the turns ratio is 2 to 1, the voltage between lines of the secondary wire will be 50 volts.

Figure 75 illustrates Y-TO-DELTA and DELTA-TO-Y connections for THREE-PHASE transformers. In this case, the voltage on the secondary is affected by the

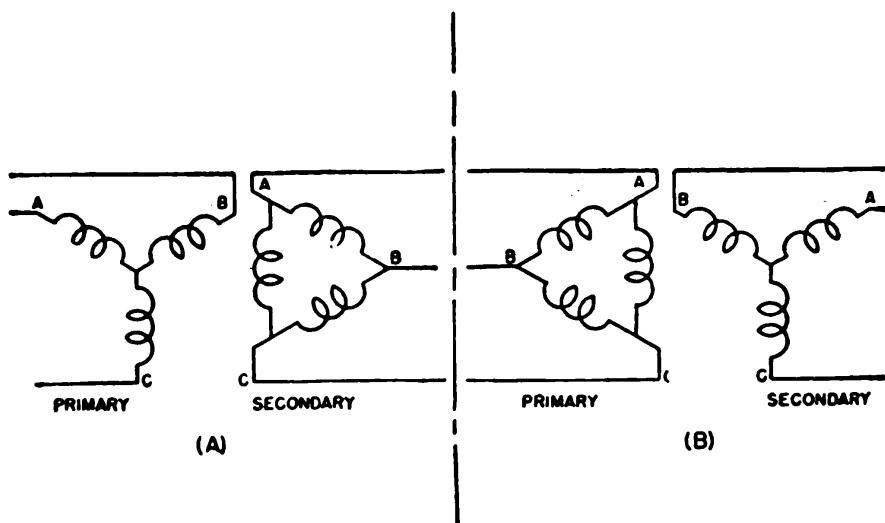
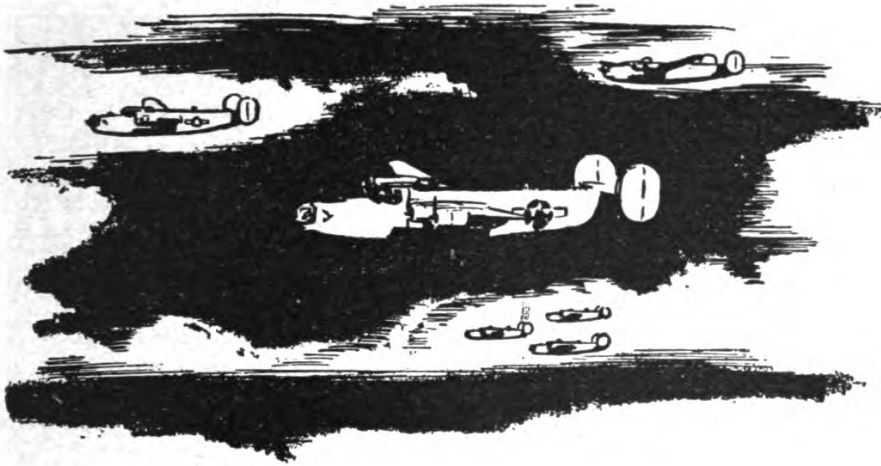


Figure 75.—Transformer connections.

method of connection, as well as by the turn-ratio. Suppose that a 1-to-1 ratio exists in each case. If you have a voltage of 173 volts between lines of the primaries in (A), then the line voltage of the secondary will be the same as phase voltage (or 100 volts).

If the 173 volts were applied to the primaries of the delta connection in (B), the secondary line voltage would be 300 volts.

Other special type connections can be used, but they are beyond the range of this book.



## CHAPTER 4

### VACUUM TUBES

#### THE HEART OF RADIO

Ever build a crystal set? Remember how you sat, earphones clamped over your ears, hunting around on a galena crystal with a cat-whisker to find a "sweet-spot" so you would hear the local radio station. Or maybe you had invested \$1.49 in that mail-order "platonium - mounted, Herzogovina - type galena crystal," and were able to pick up that station in the next town 30 miles away.

If several scientists hadn't worked and struggled to develop the vacuum tube, you'd still be hearing the Elm City Four harmonizing to you via a crystal detector. And without vacuum tubes, the telephone and many other electronic devices in industry and the home would never have reached their present wonderful development. Truly, the vacuum tube is the heart of radio and the telephone and many other useful equipments.

You probably already know the basic principles and parts of the simple diode and triode vacuum tubes. But a short, snappy review will help get you started off in step.

## SIMPLE VACUUM TUBE

In the simplest type of vacuum tube, the DIODE or two-element tube, the negatively-charged electrons driven out of the wire filament or CATHODE by the high temperature either hang around the cathode in a space-charge or are drawn across the vacuum to the PLATE. The electrons that reach the plate flow on through the circuit to the cathode for another trip across the vacuum to the plate. In doing all this travelling, the electrons generate a current, called plate current.

And remember the confusion that Ben Franklin and the other early scientists caused when they assumed that current flows from positive to negative. You know now, thanks to better instruments and knowledge of electrons and electricity, that electrons are negative particles and flow from negative to positive. In ordinary electricity and electrical devices, you should still say that current flows from positive to negative. But, as a radioman, you must also remember that ELECTRON flow is in the OPPOSITE direction to current flow, or from negative to positive.

You will run into vacuum tubes having several more parts than the simple diode tube, but the basic principles are the same—a heated metal wire coil or sleeve gives off electrons which either hang in a space-charge around the filament or manage to break through the space-charge and get to the plate. The electrons that get to the plate cause a current to be generated as they move around the circuit back to the filament for another jump.

## ELECTRONS, PROTONS, AND IONS

Everything in the universe, whether solid, liquid, or gas, is made up of ELECTRONS and PROTONS. The electrons are tiny particles carrying a NEGATIVE

charge, and the protons carry a POSITIVE charge. The ATOM in figure 76 is a tiny solar system made up of a NUCLEUS of protons and electrons with some satellite electrons revolving around the nucleus, much as the earth and other planets revolve around the sun.

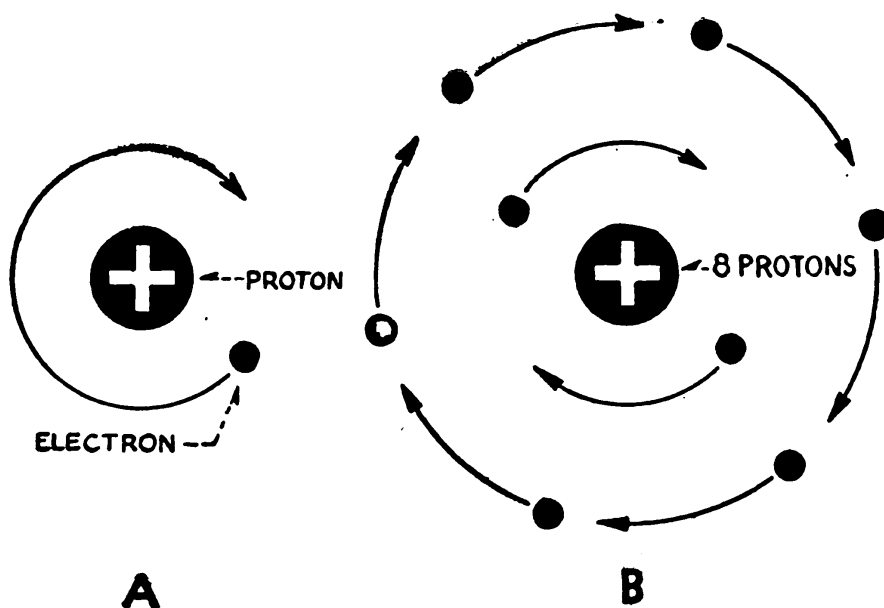


Figure 76.—Structure of hydrogen and oxygen atoms.

And what has this to do with the vacuum tube, you ask? It is almost impossible to get ALL the molecules of air or gas out of the tube when the vacuum is pulled. Hence, a few molecules will be left wandering around in the evacuated tube. Those electrons that boil out of the cathode and shoot past the space charge and across to the plate will bump into these wandering molecules of gas. And when these collisions take place, the gas molecules come off second-best. They get the electrons knocked out of them, and these electrons join the parade to the plate, knocking the electrons out of other gas molecules as they go on to the plate. IONIZATION is the name for this process of knocking electrons loose from their molecules.



Just as a collision between two automobiles uses up most of the energy being produced by each car as it moved down the road, so does the collision between an electron and a molecule use up energy. Some of the voltage across the vacuum tube is used up for the losses in energy caused by these collisions or IONIZATION. The voltage used for this purpose is the IONIZATION POTENTIAL, and varies for different gases. For example, helium has an ionization potential of 24.5 volts, neon 21.5, mercury vapor 10.39.

Since the molecule has lost an electron by ionization, you'll have an excess of positive charges on the molecule. This produces a POSITIVELY-CHARGED ION. To neutralize this positive charge, the ion is attracted back to the negative cathode. This positively-charged ion is relatively heavy and is traveling at high speed. The impact or striking force of these positive ions against the cathode surface can produce a destructive action on the cathode surface. This hammering effect is known as CATHODE BOMBARDMENT, and can quickly damage a coated cathode.

### TYPES OF CATHODES

You'll run into two types of cathodes in vacuum tubes—the direct-heated or filament type, and the indirect-heated type. The filament of the direct-

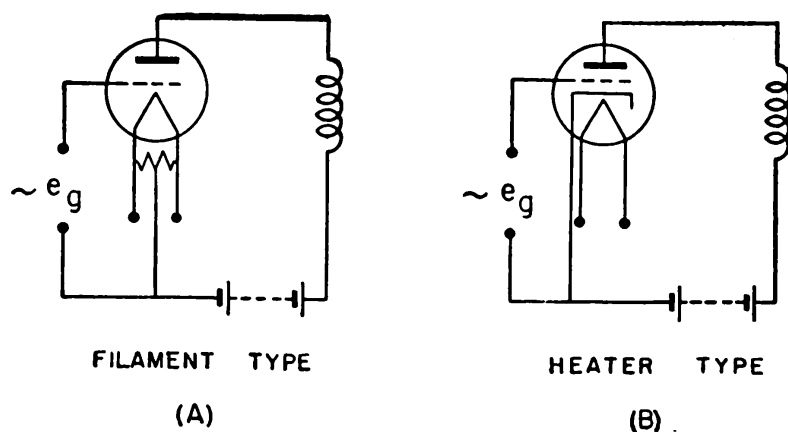


Figure 77.—Types of cathodes.

heated type is connected directly to the current supply, and is heated white hot by the passage of a.c. or d.c. through it. This type is diagrammed in figure 77A.

If you use a.c. to heat this type of filament, all parts of the cathode won't be at the same potential, because of the  $IR$  drop of a.c. The electron stream from the filament will be irregular due to this variation in potential, and you will encounter annoying hum in the tube output. You can reduce this hum greatly by connecting the return circuit from the plate and grid to a center tap on the transformer which supplies heating current to the filament. This is shown in figure 78. This center tap is always at the average potential of the whole filament. The condenser in the filament circuit forms a direct a-c connection

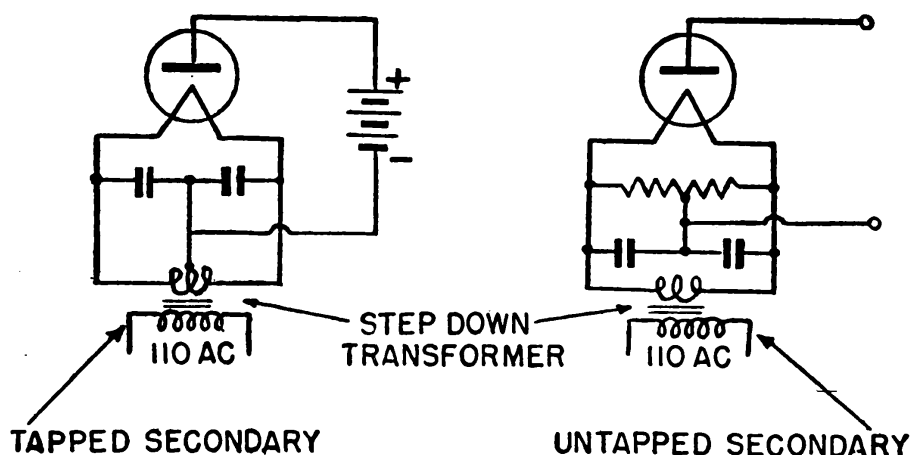


Figure 78.—Scheme for reducing hum in direct-heated filaments.

from the center tap to the heated filament. This tends to hold the filament at a CONSTANT potential, thereby reducing the hum.

The direct-heated cathode is usually coated with a layer of thorium or barium oxide to increase the emission of electrons from the wire filament at lower temperatures than would be possible with an uncoated filament.

The indirect-heated filament, figure 77B, is a metal sleeve which is made to glow and emit electrons by the heat from a direct-heated coil or "stove" placed inside the metal filament. The entire length of the indirect-heated filament is at a uniform potential, since it carries no heating current. In addition, the wires of the heater coil are so close together that practically no magnetic field is produced. The uniform potential and a lack of magnetic field combine to reduce the production of objectionable hum by this type of vacuum tube. This type of cathode is an EQUI-POTENTIAL cathode.

### PLATE CHARACTERISTICS

The plate characteristic of a diode tube can be readily found and plotted by using the circuit shown in figure 79A. As you increase the plate voltage  $E_p$ , the plate current  $I_p$  is also increased. The amount of plate current  $I_p$  will increase in proportion to the number of electrons reaching the plate from the heated cathode.

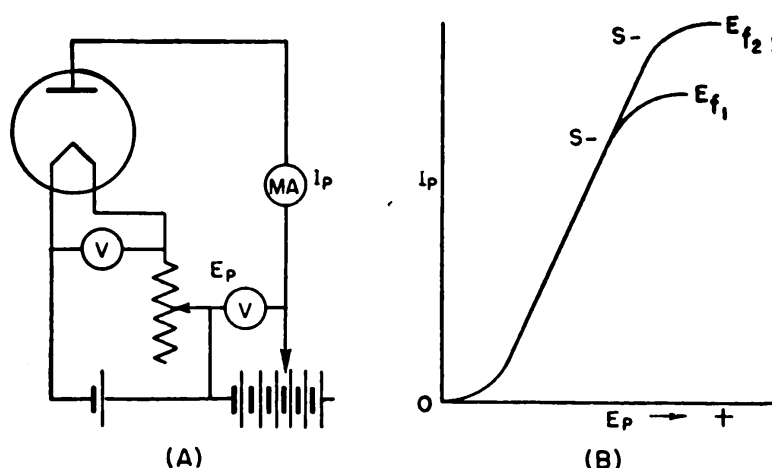


Figure 79.—Circuit diagram and characteristic curves for diode tube.

If you increase  $E_p$  from zero to a point where  $I_p$  is a maximum, you will get various values for  $I_p$ .

Plot these values of  $I_p$  and  $E_p$ , and you get a curve such as figure 79B. This is the CHARACTERISTIC CURVE for a particular diode tube. Except for the very high and very low values of  $E_p$ , the values for  $I_p$  increase in direct proportion to  $E_p$ .

What causes these bends at either end of the curves of figure 79B? When you put a small  $E_p$  on the plate, not many electrons will be able to get through the space charge and over to the plate. Since  $E_p$  is directly proportional to the number of electrons striking the plate,  $E_p$  is low. This gives you the acute sweep-back of the lower end of the curve in figure 79B.

If you increase  $E_p$ , but leave  $E_f$  constant, you increase the number of electrons that reach the plate from the filament. But you will soon reach a point  $S$  on the curve of figure 79B where ALL the electrons being emitted from the filament are drawn to the plate without loitering in the space charge.

Next increase  $E_f$ , and you increase the temperature of the filament. More electrons are boiled out and make their way across to the plate, thus  $I_p$  increases as  $E_f$  increases. This is indicated by the curves  $T_1$  and  $T_2$  on figure 79B. But there is a limit to how much voltage  $E_f$  you can put on the filament. Hence, there is a limit to the maximum value of  $I_p$ , since filament voltage  $E_f$  of a tube is usually fixed by the manufacturer.

The maximum value of  $I_p$  for a maximum value of  $E_f$  is called the SATURATION CURRENT, or EMISSION current.

## DIODES AS RECTIFIERS

By looking at figure 80, you can see how a diode can rectify a.c. to d.c. The alternator puts a voltage  $E_b$  on the plate, first in one direction, then in the opposite direction.

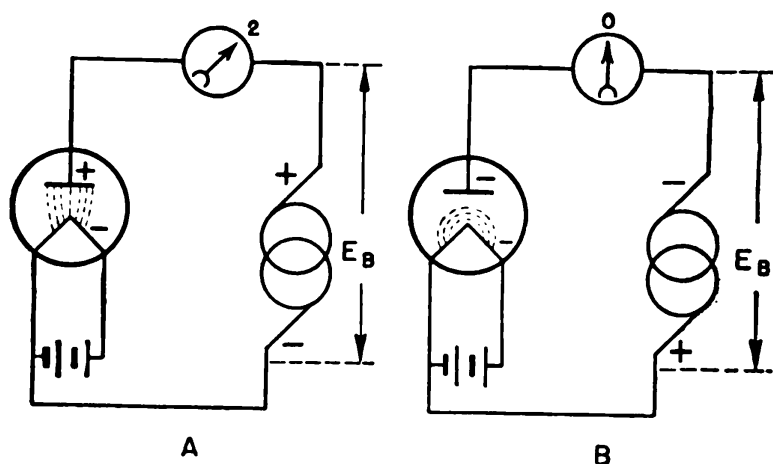


Figure 80.—Application of a-c voltage to plate.

When the a.c. is positive on the plate, electrons are drawn from the filament, and an  $I_p$  or plate current flows in the circuit, as in figure 80A. But when the alternation of a.c. puts a negative  $I_p$  on the plate, electrons are repulsed back to the plate and no current flows.

Now combine two graphs, and you will get a clear picture of rectifier action. In figure 81, you see a graph of a-c voltage input projected against a characteristic curve for a particular diode. Look at figure 81A, where you see the a.c. voltage curve as a

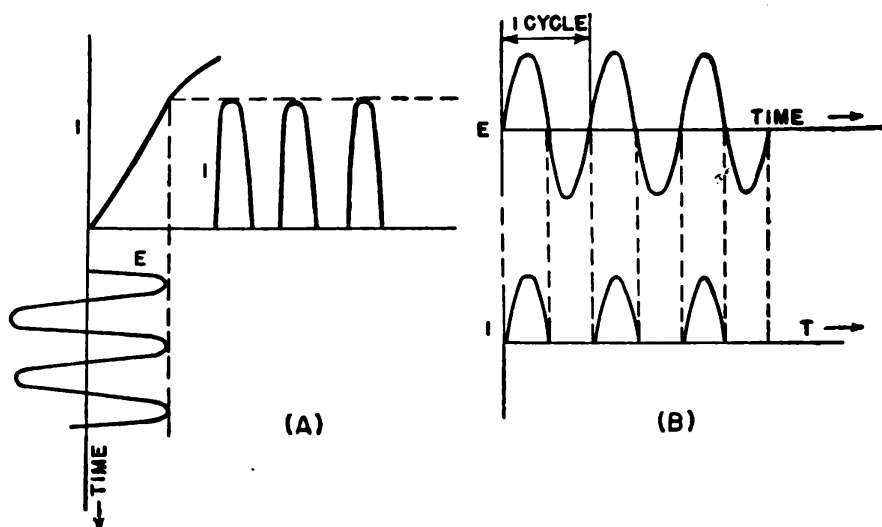


Figure 81.—Current and voltage curves of rectified a.c.

vertical sine wave. If you project this sine wave up to be reflected off the tube characteristic curve  $OX$ , you'll get a series of half-sine waves to indicate the pulsating positive a.c. of the rectifier to be. Figure 81B shows the a.c. voltage and the rectified pulsating d.c. output at the same instants of time through several alternations.

You will use vacuum tubes as rectifiers for various power supplies, and a future chapter will discuss rectifiers at greater length.

### TRIODE TUBES

In a TRIODE vacuum tube, you'll find a third part in addition to the two elements of the diode. The triode has a GRID between the cathode and the plate

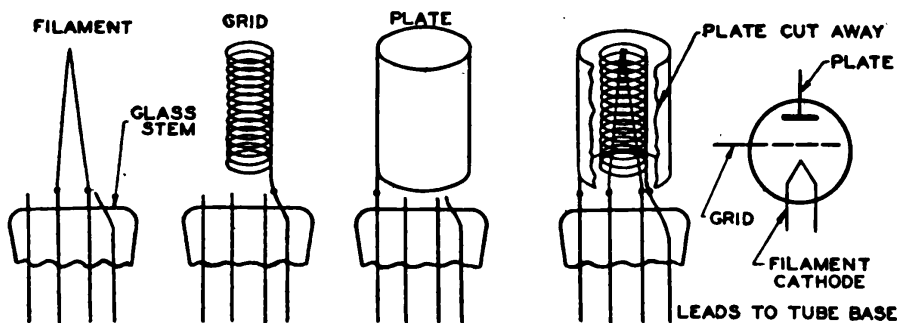


Figure 82.—Parts of a triode, with glass envelope removed.

shown in figure 82. This grid is made of fine wire screen or a series of fine spiral wires so that the electrons from the cathode can pass through the grid to the plate. The grid is normally at a negative potential, and so does not attract the negative electrons on their jump from cathode to plate. Thus, no grid current is normally produced.

Since the grid is set quite close to the cathode, the grid voltage  $E_g$  exerts a powerful controlling influence on the flow of electrons to the plate. Variations of grid potential strongly affect the flow of electrons to the plate, and cause variations in plate current  $I_p$ .

## MUTUAL CHARACTERISTIC CURVES FOR TRIODE

You can get data for plotting mutual characteristic curves of triodes by using the circuit shown in figure 83A. As you vary the grid voltage  $E_g$  by moving the tap on the C-battery, you cause variations in plate current  $I_p$  which give you readings of  $E_g$  against  $I_p$ .

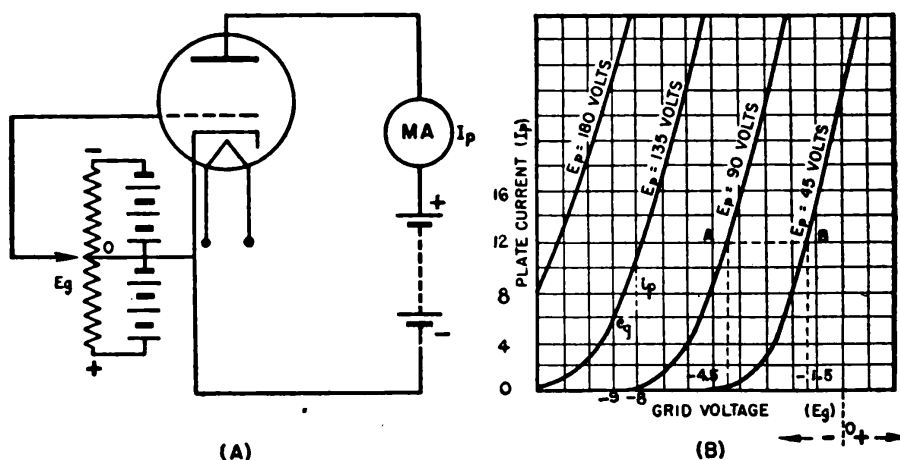


Figure 83.—Mutual characteristic curves of triodes.

The four curves of figure 83B were obtained by taking four different values of  $E_p$ , and varying  $E_g$  through several voltages, keeping  $E_p$  constant at each of the four values. You now have characteristic curves for a triode under four different plate voltages. These are STATIC curves, since the triode was under zero load. Curves for tubes under load are DYNAMIC characteristic curves.

Note that in figure 83B almost all the values for  $E_g$  are negative, nevertheless, some plate current flows except when the grid is quite negative to the point of finally stopping ALL flow of electrons from cathode through grid to plate. The point where all  $I_p$  ceases to flow is called CUT-OFF. You'll see that as  $E_p$  becomes HIGHER, the  $E_g$  cut-off voltage grows more NEGATIVE.

You will find tube characteristic curves important

and useful in the design of circuits and the applications of tubes to circuits. You can obtain characteristic curves with the apparatus of figure 83A, although tube manufacturers supply a sheet of data and characteristics with most tubes.

### GRID BIAS

It will often be necessary for you to hold  $E_g$  of your triode to a fixed negative voltage with respect to the cathode voltage  $E_k$ . You do this by **BIASING THE GRID** by one of the systems shown in figure 84.

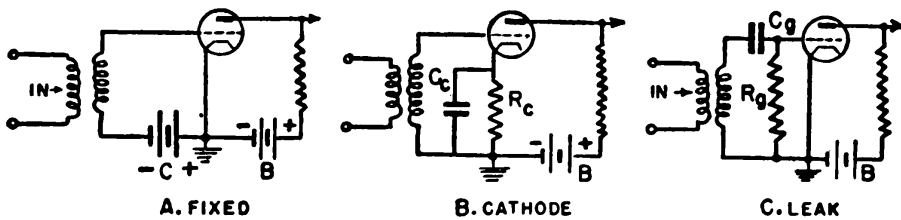


Figure 84.—Grid-bias supply circuits.

Here is why you need grid-bias, and how it works. If the grid becomes positive, electrons from the cathode will be drawn to the grid, and a current will flow through the grid circuit. This stray grid current will distort the plate circuit reproduction of any signal you put through the tube. In figure 85A, the **BIAS VOLTAGE** is too **SMALL**. The positive signal voltage applied to the grid is **GREATER** than the negative bias voltage. When the grid becomes positive, it also draws electrons, and loses control of the  $I_p$  flowing to the plate, with the result that the top portion of the signal is clipped off. In figure 85B, the bias voltage is too **LARGE** and the negative signal voltage drives the tube beyond cut-off, thus clipping off the bottom portion of the signal. In figure 85C, the bias voltage is **CORRECT**, and the signal in the plate circuit is a **TRUE** reproduction of the grid signal.

In figure 84A, you see the method of applying



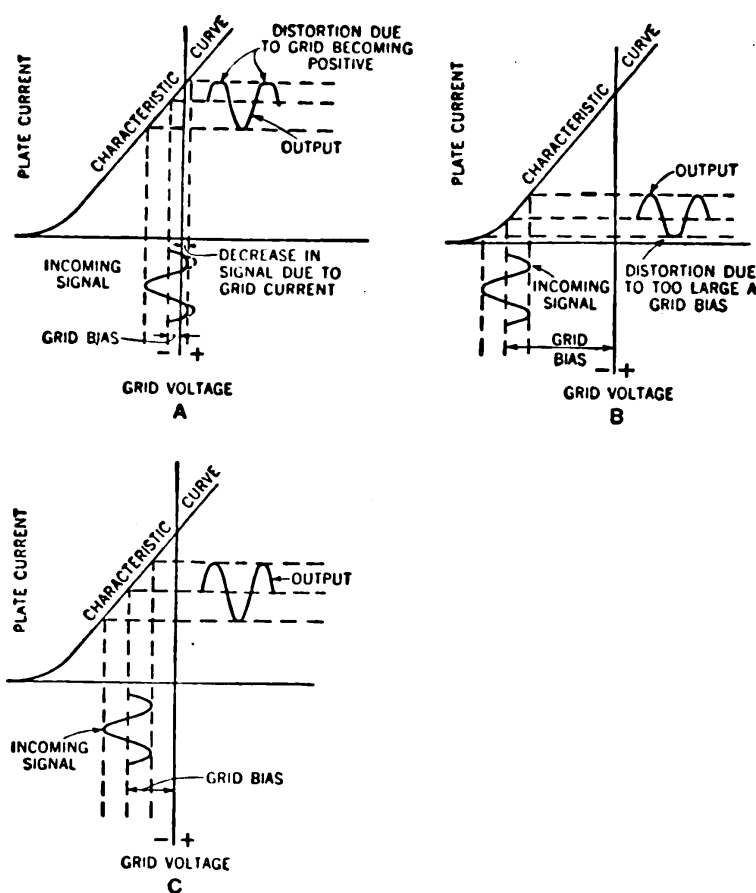


Figure 85.—Effects of grid currents.

FIXED or "C"-battery GRID-BIAS. A "C"-battery, usually 4.5 volts, is put in the grid circuit to impress a negative voltage or  $-E_g$ . This method is heavy, bulky, and requires frequent replacement of "C"-batteries. It is used most on portable radio equipment, where no other power supply is available.

CATHODE GRID-BIAS is shown in figure 84B. Plate current, which is opposite in direction to electron flow across the triode, flows down through the resistor  $R_c$ , and produces a potential drop that makes  $E_g$  negative to  $E_f$ . The condenser  $C_c$  is the CATHODE BY-PASS CONDENSER, and reduces the negative feedback by shunting a.c. or high-frequency currents around resistor  $R_c$ .

GRID-LEAK BIAS is applied in figure 84C by putting resistance  $R_g$  in series with the grid circuit, and in

parallel with condenser  $C_g$  to prevent grid current from flowing through the transformer secondary. When the grid goes positive with respect to the cathode, electrons are drawn to the grid. They flow through  $R_g$  and make the top or entering end of the resistor negative to the bottom, and bias the grid. This set-up is useful only when you have strong and CONSTANT INPUT SIGNALS that will keep a voltage on the grid. Otherwise, the grid bias will drop to zero whenever there is no current through  $R_g$ . The tube will draw an over-high  $I_p$ , and will be damaged. You will find this type of bias in wide use in transmitter amplifiers.

### TUBE CHARACTERISTICS

There are three important ratios that will help you analyze vacuum tube performance. They are: Voltage amplification constant, internal plate resistance, and mutual conductance.

VOLTAGE AMPLIFICATION CONSTANT is the ratio of effectiveness of changes of grid potential  $E_g$  and plate potential  $E_p$  in changing plate current  $I_p$ . The symbol for voltage amplification constant is " $\mu$ " (pronounced "mew"). To put this ratio into a formula,

$$\mu = \frac{E_{1p} - E_{2p}}{E_{2g} - E_{1g}} = \frac{e_p}{e_g}$$

when  $I_{2p} - I_{1p} = 0$ .

Or  $\mu$  may be defined as the ratio of change of plate voltage ( $E_{1p} - E_{2p}$ ) to change of grid voltage ( $E_{2g} - E_{1g}$ ) for zero change in plate current ( $I_{2p} - I_{1p} = 0$ ).

Look at figure 83 to see what " $\mu$ " really means. For the triode whose characteristic curves are shown, a change in plate voltage  $E_p$  from 90 v. to -45 v. is overcome by a change (A - B) in grid voltage  $E_g$  from

—4.5 v. to —1.5 v., while plate current  $I_p$  remains constant at a value of 12 milliamps. So—

$$\mu = \frac{(90 - 45)}{[-1.5 - (-4.5)]} = \frac{45}{3} = 15$$

The value of  $\mu$  varies for various types of tubes, and ranges between 1 and 100, the usual value being about 10.

INTERNAL TUBE RESISTANCE  $r_p$ , also called A.C. PLATE RESISTANCE, is the resistance set up by the space charge and the negative grid charge to the flow of electrons from cathode to plate. You can use an adaptation of Ohm's Law to develop a formula

for  $r_p$ . Thus, instead of  $R = \frac{E}{I}$ , you can write

$$r_p = \frac{e_p}{i_p} \text{ where } r_p \text{ is the PLATE RESISTANCE, } e_p \text{ is the}$$

CHANGE in voltage on the plate, and  $i_p$  is the CHANGE in plate current. Values of  $r_p$  for triodes range between 800 and 150,000 ohms, and can usually be obtained for specific tubes from the data supplied by the manufacturer, as well as from the tube characteristic curves.

A third tube ratio that you will find useful is MUTUAL CONDUCTANCE,  $g_m$ . The CHANGE in  $I_p$  for a CHANGE of 1 volt in  $E_g$  when  $E_p$  is held constant will give you  $g_m$ , thus—

$$g_m = \frac{i_p}{e_g}$$

where  $i_p$  is the CHANGE in  $I_p$ , and  $e_g$  is a CHANGE of 1 volt in  $E_g$ . The unit for  $g_m$  is the MICRO-MHO, and triodes vary in mutual conductance between 200 and 5,000 micro-mhos. For example, a triode whose  $I_p$  changes 2 ma. with a 1-volt change in  $E_g$  would have

$$g_m = \frac{2 \text{ ma.}}{1 \text{ v.}} = 2,000 \text{ micro-mhos, in figure 83B}$$

on the curve for  $E_p = 135$  volts. Mutual conductance  $g_m$  is the measure of the efficiency of the grid in controlling the plate current  $I_p$ . Therefore,  $g_m = \frac{\omega}{r_p}$

### INTER-ELECTRODE CAPACITANCE

Whenever you have two conductors separated by a dielectric or nonconductor, you produce a condenser effect. This is the effect between each pair of the three elements of the triode. You thus get INTERELECTRODE CAPACITANCE between grid and cathode ( $C_1$ ), and grid and plate ( $C_2$ ), and cathode and plate ( $C_3$ ), as indicated in figure 86B. Although these capacitances are small, they can still prove troublesome by causing undesirable linking of the input and output circuits. This linking is known as FEED-BACK, and is severest between the grid and plate. It causes instability of signals and unsatisfactory triode performance in r-f amplifiers.

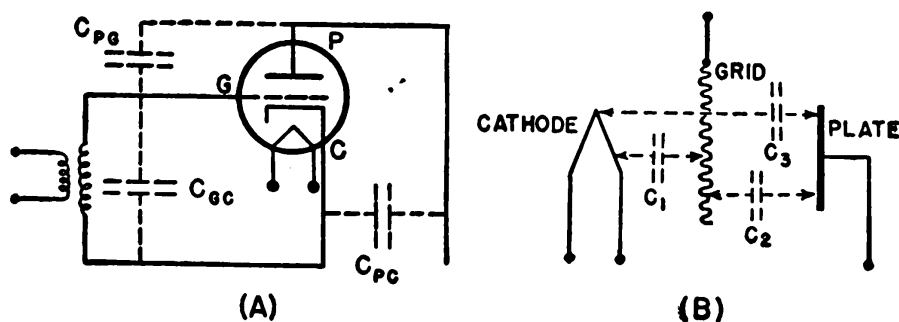


Figure 86.—Inter-electrode capacitance.

Since the triode plate carries a positive charge from the B-battery, any variations of  $I_p$  as a result of a signal input on the grid will cause fluctuations in  $E_p$ . Now if you consider the plate and grid as two plates of a condenser, the positive charge on the tube plate will cause electrons to accumulate on the grid. Thus, the grid becomes negative. The greater the positive charge on the plate, the more negative the

grid becomes and the greater is the collection of electrons on the grid.

You see now what is happening by looking at figure 86A. As the plate charge becomes more positive, more electrons flow through the r-f transformer to the grid. Then as the plate loses some of its + charge, some electrons are forced out of the grid and back through the r-f transformer secondary. This fluctuation of plate voltage sets up oscillations in the grid circuit which cause objectionable distortion, especially in the high frequencies.

### GETTING RID OF IT

There are several ways to make this inter-electrode capacitance in the triode behave itself. The best way is by using a NEUTRALIZATION circuit to prevent oscillation. There are three types of neutralization—plate-neutralization, grid-neutralization, and inductive-neutralization.

PLATE-NEUTRALIZATION is the most satisfactory type, and is done by inserting a variable condenser

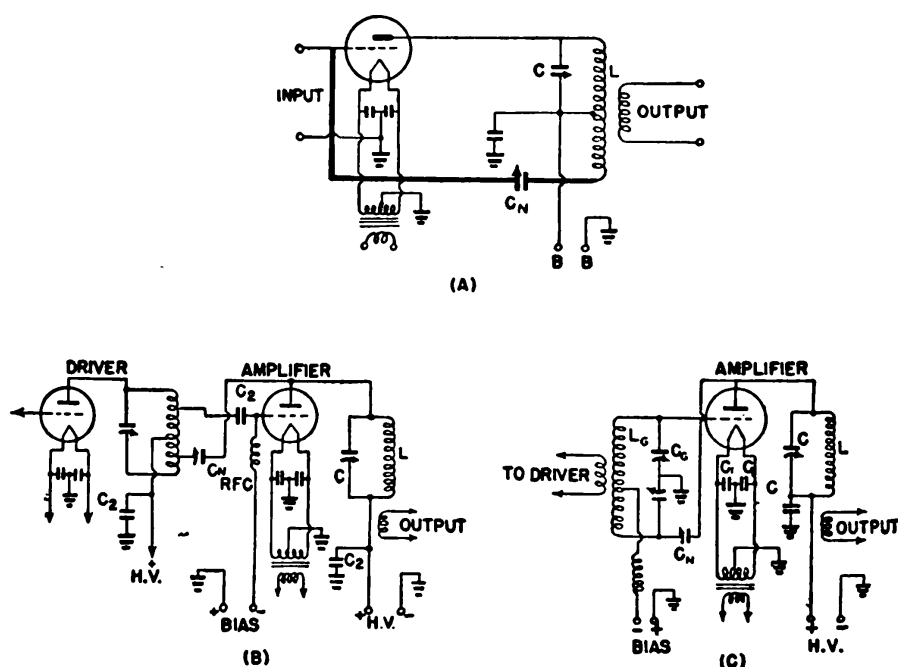


Figure 87.—Neutralization of inter-electrode capacitance.

$C_N$ , figure 87A, in the grid-to-plate circuit. In this neutralization circuit, voltages are induced in coil  $L$  by the r.f. voltages in the circuit  $L$ - $C$ . These induced voltages in  $L$  are opposite in polarity to those on the grid which caused them originally. They are fed back to the grid through neutralizing condensers  $C_N$  to offset the voltage which is put on the grid through the grid-to-plate inter-electrode capacitance of the triode. Since condenser  $C_N$  is variable, you tune it to make its capacity equal to the interelectrode capacitance between the plate and grid.

There are several other types of neutralization for inter-electrode capacitance. GRID NEUTRALIZATION is shown in figure 87B. It is similar in operation to plate neutralization, except that you feed the neutralizing voltage from the grid circuit TO the plate.

In many transmitters, you'll find DIRECT plate-to-grid neutralization of the type shown in figure 87C. The condenser  $C$  and inductance  $L$  make up the neutralizing circuit. Here, the condenser is in series with the inductance so that the plate voltage  $E_p$  is not impressed on the tube grid. The current from plate to grid through the condenser-inductance circuit is  $180^\circ$  out of phase with the current ACROSS the dielectric between plate and grid. By picking the proper value for inductance  $L$ , you can make the resultant two voltages on the grid equal and out of phase. Thus, you will neutralize the voltage across the dielectric with the voltage through  $C$  and  $L$ .

You may also run into other types of neutralization, but the principles will be the same as one of those you've just met above.

## TETRODES

If you add a SCREEN GRID to the three elements of the triode, you make a TETRODE, which is a vacuum tube with FOUR elements. This screen grid serves as

an electrostatic shield reducing the inter-electrode capacitance between the plate and the control grid, in figure 88, and prevents feed-back from grid to plate. Adding the screen grid to the tube greatly improves the stability of a tube that is to be used as an amplifier. But you'll hear more radio men refer to tetrodes as SCREEN-GRID TUBES. Same thing, though.

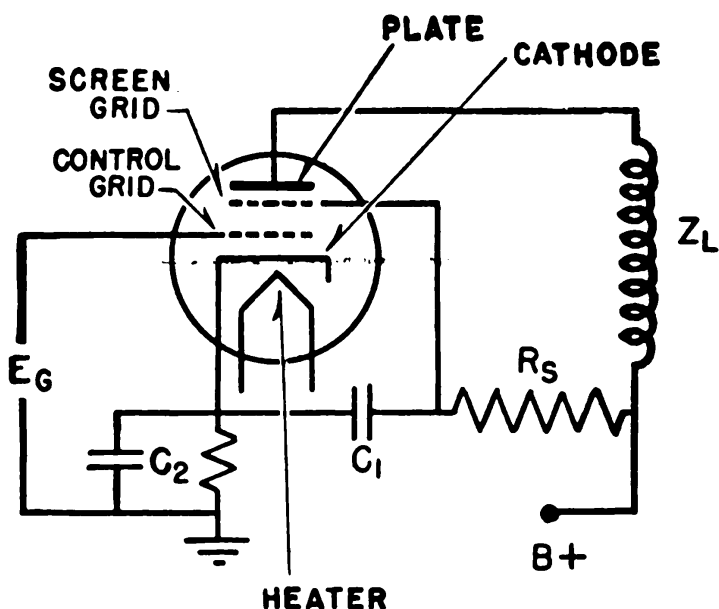


Figure 88.—Tetrode circuit.

So that some electrons will flow past the screen grid, you charge the screen grid to positive potential. Since the screen grid shields the control grid from variations of plate voltages  $E_p$ , it is logical that the screen grid also shields the cathode from the plate. Thus, the emission of electrons from the cathode is affected only very slightly by the plate voltage, but is determined almost altogether by the voltages on the screen grid and the control grid. A small part of the electron flow goes to the screen grid, since it is positive, and forms the screen-grid current  $I_{sg}$ . The remainder of the electrons flow to the plate.

One advantage of the tetrode is its high plate resistance, approximately 1,000,000 ohms, which is caused by the fact that a large change in  $E_p$  causes a very small change in  $I_p$ . As a result,  $R_p$  is quite high, about 1,200,000 ohms (1.2 megohms) for certain tetrodes, compared to 3,600 ohms for a companion triode. Likewise, the amplification factors ( $\mu$ ) for tetrodes are a good deal higher than those for triodes, since  $\mu$  for some tetrodes runs as high as 780. Mutual conductance ( $g_m$ ) for tetrodes is about the same, although the value of  $g_m$  for tetrodes is reduced a small amount by the diversion of electrons to the screen grid.

### TETRODE CHARACTERISTICS

Before you can learn much about the characteristics of a tetrode, you'll have to hear about SECONDARY EMISSION.

Some of the electrodes driven off the cathode are moving at a high rate of speed when they strike the plate. Their impact knocks off electrons in the surface of the plate, and these SECONDARY electrons fly out into the vacuum between the screen grid and the plate. This knocking-off process is called SECONDARY EMISSION.

In a triode, secondary emission causes no trouble, since the secondary electrons knocked off the plate are driven back to the plate by the negatively-charged grid. However, secondary electrons kick up some trouble in a tetrode. Here's what happens.

The negative secondary electrons that are hammered out of the plate fly out into the space between the plate and the screen grid. But since the screen grid is charged positive with respect to the cathode, the secondary electrons are drawn to the screen grid, and a reverse current flows from screen to plate. This effect is especially marked when the values of  $E_p$  and  $E_{sg}$  are about equal, as during that part of



the a-c cycle when  $I_p$  instantaneous is large and  $E_p$  is low.

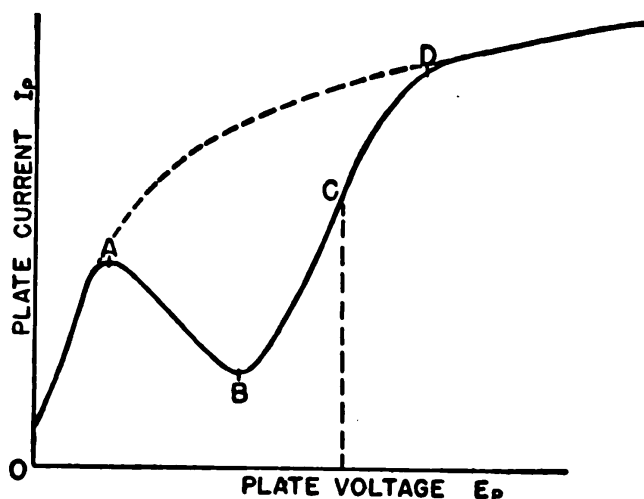


Figure 89.—Characteristic curve for tetrode.

Look at figure 89, which is the characteristic curve for a certain tetrode. The pronounced dip in this curve between points  $A$  and  $D$  is caused by secondary emission. The curve between  $O$  and  $A$  rises normally, since the velocity of electrons as they strike the plate isn't sufficiently high to knock many secondary electrons out of the plate.

Above point  $D$ , great numbers of secondary electrons are emitted, but  $E_p$  is so much greater than  $E_{sg}$  that all the electrons knocked out of the plate are drawn back to the plate. Hence the screen grid is not loaded with secondary electrons, and no reverse current flows from screen to plate. There is no loss of  $I_p$ .

But between points  $A$  and  $C$ , secondary emission really kicks up. The reverse flow of current from screen to plate causes a dip in the curve from  $A$  to  $B$ . At  $C$ ,  $E_p$  and  $E_{sg}$  are equal, and the decrease in  $I_p$  between  $C$  and  $D$  is the result of the initial velocity of the secondary electrons. If this velocity is high enough, it will overcome the opposing electrostatic field set up by the higher value of  $E_p$ , and the plate

will continue to lose electrons to the screen grid, as shown by the curve between points *C* and *D*.

A coating of graphite and carbon on the plate will reduce the amount of secondary emission from the plate, and will reduce the dip in the characteristic curve between points *A* and *D*.

The shielding action of the screen grid is increased by inserting by-pass condensers  $C_1$  and  $C_2$ , in figure 88, in the circuit between the screen grid and the control grid. The combination of condensers and screen grid reduces the grid-to-plate capacitance of a tetrode to a very low figure. Actually, this capacitance is reduced from about  $8.0\mu\mu\text{f.}$  for a triode to less than  $0.01\mu\mu\text{f.}$  for a screen-grid tube.

### VOLTAGE FOR SCREEN-GRID

Look back again to figure 88 to see how you obtain a positive voltage supply for the screen grid from the *B*-supply. By running the *B* voltage supply through resistance  $R_s$ , you reduce the screen-grid voltage to the necessary value. The flow of current through the screen-grid and resistance  $R_s$  creates this voltage drop.

But wait! As the control-grid voltage increases, the screen-grid current  $I_{sg}$  increases, causing an increased voltage loss across  $R_s$ . The result is a drop in screen-grid voltage  $E_{sg}$ , which causes a drop in plate current  $I_p$  just at the instant when  $I_p$  should be increasing because of signal action. So you'll have to fix it somehow.

Put a condenser  $C_1$ , in figure 88, in the control-grid circuit so that any fluctuations in  $I_{sg}$  are by-passed through to the cathode, and do not flow through  $R_s$ . In this way, if you use a large condenser in  $C_1$ , the screen-grid voltage  $E_{sg}$  will be held practically constant.

## THE PENTODE

You can overcome the effect of the acute dip in tetrode plate characteristic curves by adding another grid to the tetrode next to the plate. The tetrode now becomes the PENTODE, and the third grid is the SUPPRESSOR GRID. This grid has larger openings in the screen than the other two grids have, and is usually connected to the cathode, as in figure 90. Its potential is at zero. It drives the low-velocity secondary electrons back to the plate, yet does not hinder the flow of primary electrons in the regular cathode-to-plate stream. Even at low plate voltages,

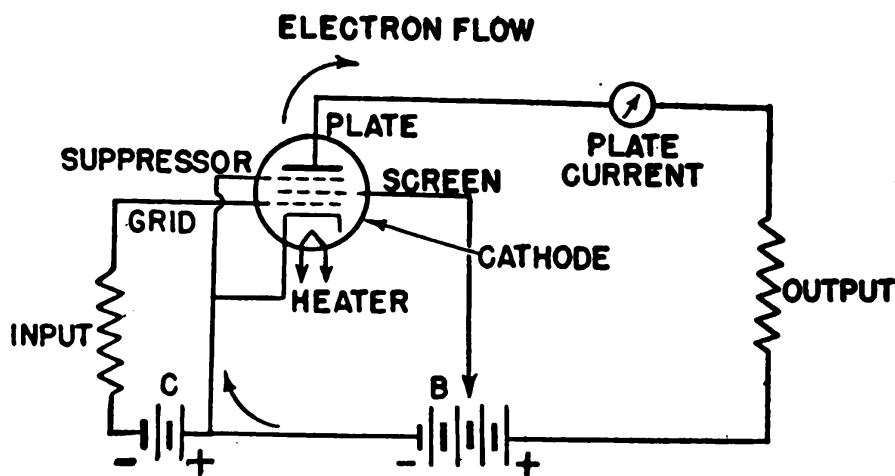


Figure 90.—Pentode circuit.

the field between the plate and the suppressor grid is in the right direction to drive electrons toward the plate, and make the secondary electrons return to the plate.

Values of  $\mu$  (amplification factor), mutual conductance, and plate resistance are approximately the same for pentodes and tetrodes of similar capacities. Both  $\mu$  and  $r_p$  for both types of tubes are high. As a result, the high values of  $r_p$  make high voltage amplification possible with either type of tube.

To prevent feed-back and instability between the input and output leads of pentodes and triodes, the

leads must be carefully shielded or separated from each other. This is usually done by taking the connection to the control grid out to a cap on top of the tube, while the other connections are taken out through the usual prongs in the tube base.

### SHARP CUT-OFFS AND VARIABLE MU

Certain types of pentodes are designed specially to handle large signal voltages without distortion in circuits using grid-bias control to vary the mutual conductance and the amplification. The physical structure of the grid is designed to provide a modification of the mutual characteristics of the tube. Such tubes are called VARIABLE-MU and SHARP CUT-OFF pentodes.

In the variable- $\mu$  tube, an increase in negative grid-bias causes a decrease in the  $\mu$ , or amplification factor. A similar type of tube—the sharp cut-off type—has practically constant  $\mu$ , no matter how much the grid

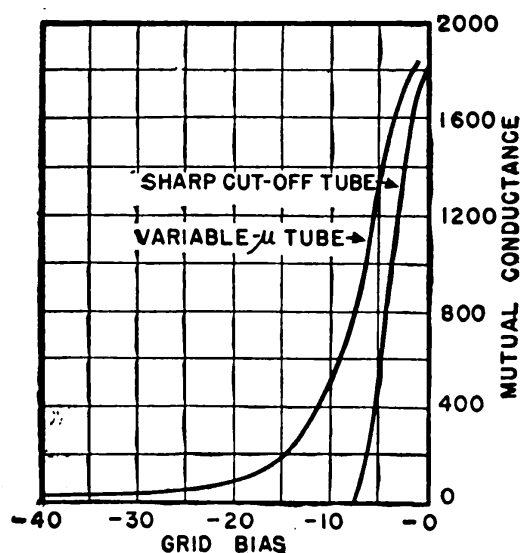


Figure 91.—Curves of  $g_m$  vs  $E_g$ .

bias varies. A look at the characteristic curves in figure 91 for a typical sharp cut-off pentode and a variable- $\mu$  pentode will show you their various control qualities. You can see that the tube will be

blocked, when the grid voltage on the sharp cut-off tube reaches  $-7$  volts, and no signal will pass through the set. Notice the difference in cut-off voltage of the variable tube. Even when the bias voltage is as large as  $-40$  volts, the tube is not cut-off and the set will continue to operate, but at greatly reduced volume.

The variable- $\mu$  tube is used with receivers using AUTOMATIC VOLUME CONTROL. When strong biasing voltages are sent back to a sharp cut-off tube, the set will automatically be cut on and off, and will produce a putt-putt sound known as MOTORBOATING. The variable- $\mu$  tube permits a smooth, even control of any signal strength fluctuations.

### BEAM POWER TUBES

Another high-efficiency tube is the BEAM TUBE, in which beam-forming plates in the tube are shaped to throw a concentrated beam of electrons from the cathode onto the plate. In figure 92, you see a cut-away drawing of beam tube construction. The tube can be either a tetrode or a pentode, with a cathode,

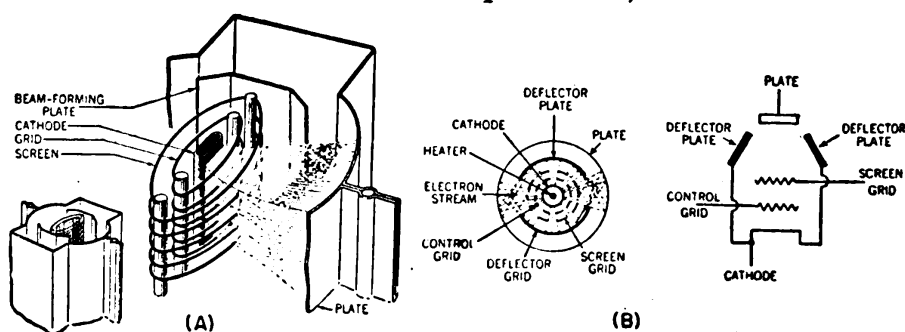


Figure 92.—Beam-power tube construction.

control grid, screen grid, plate, and even a suppressor grid. However beam power tubes are usually tetrodes.

In addition, the tube has beam-forming plates, connected to the cathode and operated at cathode potential. Secondary electrons from the plate are prevented by the beam-forming plates and the plate

space-charge from returning to the screen outside the beam, and for many purposes a suppressor grid is unnecessary to counteract the distortion of secondary emission.

Beam power tubes use low screen current. They also make effective use of space charge to provide suppression. Hence, the beam power tubes are highly efficient, and have high power output and sensitivity.

### MULTI-PURPOSE TUBES

A large variety of combination tubes have been built to handle two or more jobs, especially in re-

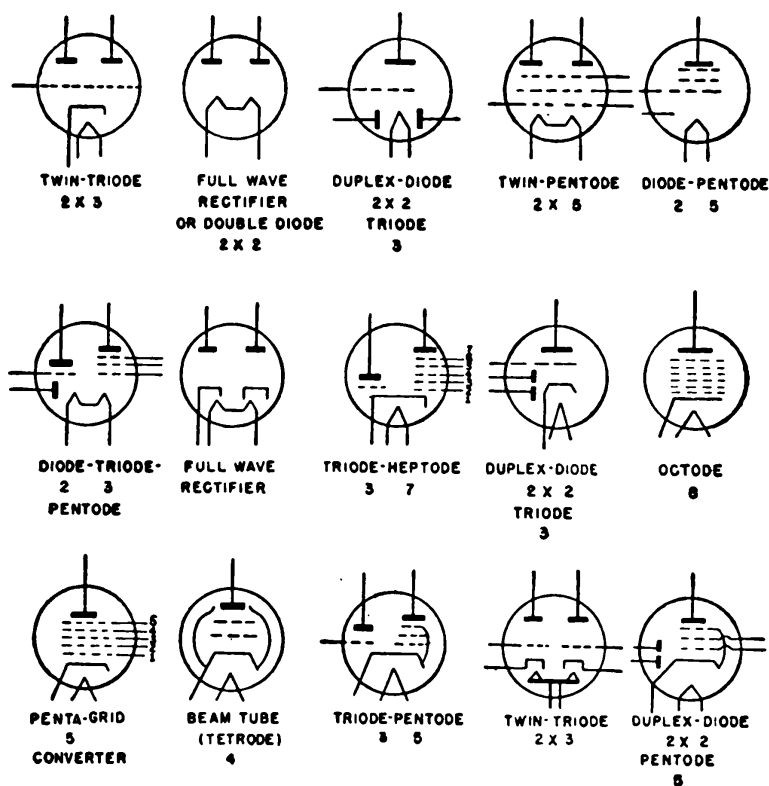


Figure 93.—Multi-purpose tubes.

ceivers. These tubes are frequently made up of two or three tubes mounted in one glass or metal envelope, yet each acts independently of the other. In figure 93, you see the schematic outlines of a number of multi-purpose tubes. The names are usually descriptive of their functions.

A typical multi-purpose tube is the PENTAGRID CONVERTER (Type 6A8) used as a combination first detector and oscillator in superheterodyne receivers. A schematic diagram is shown in figure 94.

Here's a summary of what goes on inside the envelope of a 6A8.

Grids 1 and 2 serve as grid and anode respectively of a triode oscillator. Grids 3 and 5 are connected

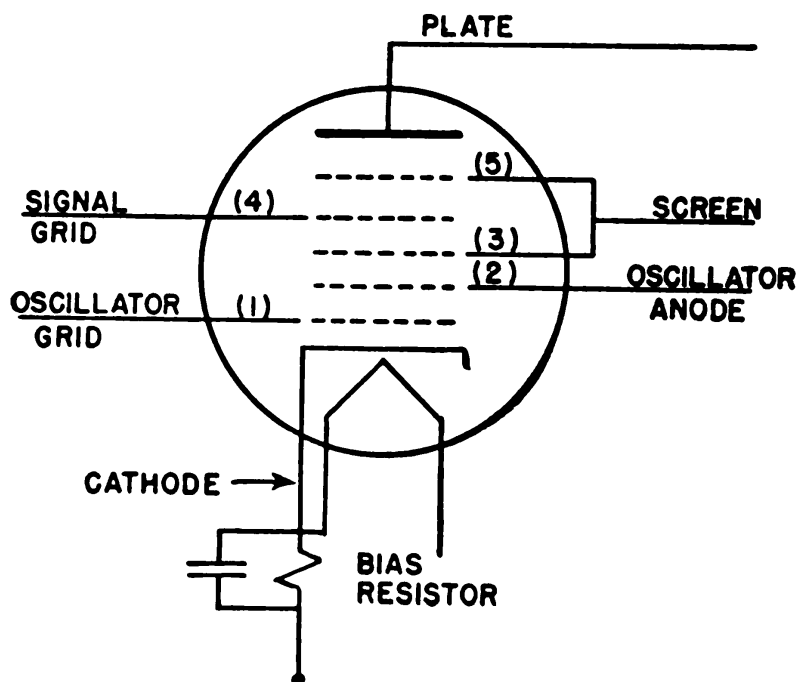
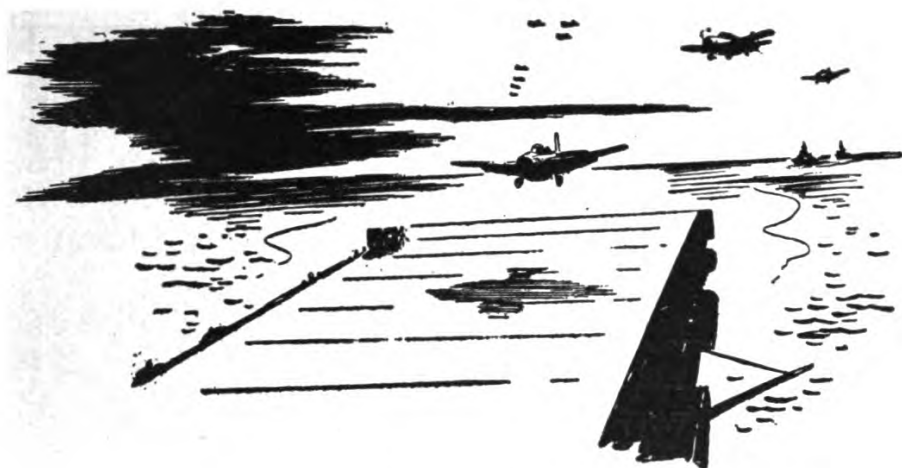


Figure 94.—Pentagrid converter.

together and shield grids 2 and 4 from each other and from the plate. Grid 4 receives the input signal. The a-c voltage of No. 4 modulates the electron flow passing from the oscillator section of the tube to the plate. The plate current is then a combination of the effects of the oscillator and signal voltages. The only coupling between the two sources is by electron flow. Electrically the two circuits are isolated by the shielding action of screen grids 3 and 5.

Briefly, that gives you a picture of how the various parts of a multi-purpose tube are made to do more than one job.



## CHAPTER 5

### VACUUM-TUBE AMPLIFIERS

#### PUSHING 'EM UP

Remember how a vacuum tube amplifies? In a triode, you use a small input voltage on the grid to control a large output current in the plate circuit. You can amplify voltages of almost any frequency with vacuum tubes. And you can get whatever amplification you need by lining up your tubes in CASCADE, so that the amplification of each tube in the cascade multiplies the previous amplifier output.

POWER AMPLIFIERS are designed to develop as much POWER as possible to supply a loud speaker or similar power-operated unit. In power amplifiers, VOLTAGE amplification is of no importance and is usually kept low to increase the POWER amplification. The final stage of an amplification cascade in a receiver is usually a POWER amplifier to drive the loud speaker.

In contrast, you use a VOLTAGE AMPLIFIER to develop as much amplified voltage as possible with a very small power output. You run the signal input voltage through a cascade of voltage amplifier tubes to step up the weak signals and deliver maximum



amplified voltage to the final or POWER stage for conversion into a strong power impulse.

AUDIO-FREQUENCY (a.f.) amplifiers are used to amplify electronic waves in the range of 15 to 15,000 cycles per second. Waves in this range are converted directly into audible sound waves or air vibrations that can be picked up by the human ear.

RADIO-FREQUENCIES (r.f.) are waves about 15,000 cycles per second, and on up to 60 billion cycles per second. R.F. waves are above the range of sound audible to the human ear.

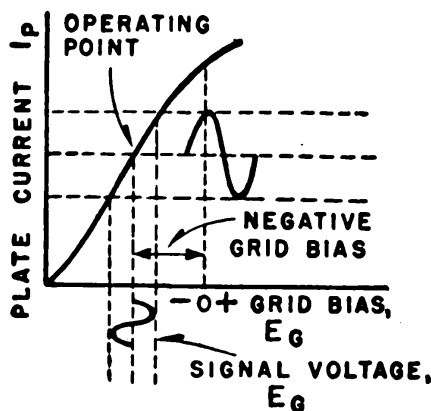
And a newcomer is VIDEO FREQUENCY (v.f.) covering special conditions of television and other new electronic devices. V.F. lies in the range of 15 to 1 million cycles, covering both a.f. and r.f. bands.

### THE THREE CLASSES

You'll run into three main classes of amplifiers, divided according to the work they do and their operating conditions. Here they are—

#### CLASS "A" AMPLIFIER

This amplifier is used with its grid bias and grid voltages set so that plate current flows at all times.



#### CLASS A

Figure 95.—Characteristic curve for class A amplifier.

The grid voltage is never driven positive or beyond cut-off by the input signal, and is never driven so far negative that plate-current cut-off is reached. Look at figure 95.

### CLASS "B" AMPLIFIER

Here you make the grid bias approximately equal to the cut-off value of the tube, so that the plate current is about zero when no exciting grid voltage is on the tube. Thus plate current will flow for

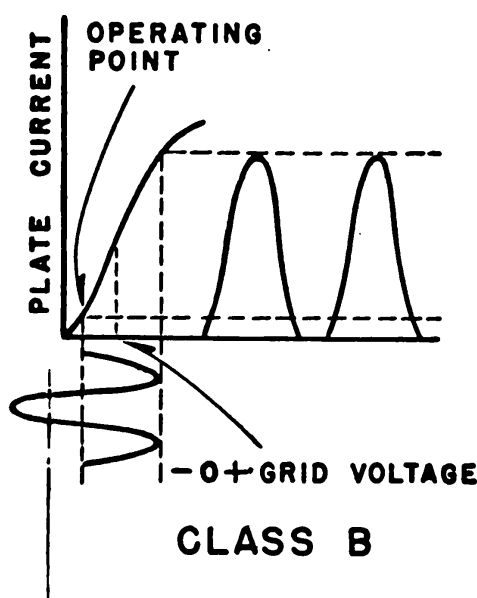


Figure 96.—Characteristics of class B amplifier.

approximately a half cycle when an alternating grid voltage is applied. See figure 96.

### CLASS "C" AMPLIFIER

In class C amplifier, figure 97, you make the grid bias a good deal larger than the cut-off value of the tube, so that the plate current is zero when no alternating grid voltage is being applied. Plate current will flow in the tube for much less than one-half of each cycle when you apply an alternating grid voltage.

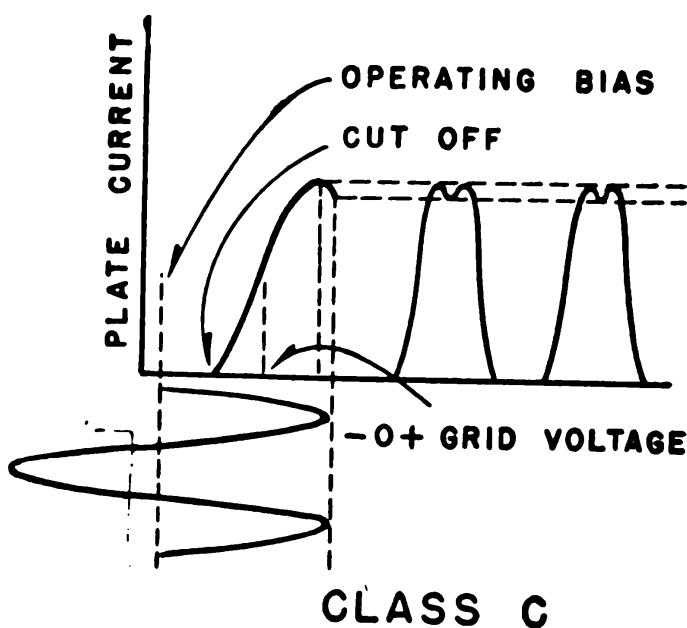


Figure 97.—Class C amplifier wave.

### WHERE YOU USE THEM

For r.f. amplifiers that operate ahead of a selective circuit, as in a transmitter, or that operate where you don't object to distortion, you can use either A, B, or C as a single-tube amplifier or in push-pull.

When you come to a.f. amplifiers, however, you have to avoid as much distortion as possible, so you use only class A amplifiers in single stage. You can get rid of even more distortion by using your class A amplifier in push-pull with audio circuits. Power performance is better, too.

By using two tubes in a balanced amplifier stage, you can use class B for audio service.

And now you're ready to learn in detail about each of the three classes of amplifiers.

### CLASS "A" VOLTAGE AMPLIFIER

You can use a vacuum tube to reproduce variations in grid voltage waves across an impedance or resistance in the tube plate circuit. Basically, these

variations have the same form and frequency as the input signal-voltage waves, but are AMPLIFIED—taller from base to peak. You do this amplifying by putting enough grid bias on the tube to operate at the center of the linear portion of the characteristic curve to turn out plate current variations proportional to the signal variations. You get a much larger plate voltage variation than the input grid-voltage, and the result is AMPLIFICATION of the signal.

Look back at figure 95, and you'll see the characteristic curve of plate current  $I_p$  vs. grid voltage  $E_g$  for a vacuum tube, and the amplification you get by applying a signal,  $S$ , to the grid of this tube. In a simple amplifier using this particular tube, as  $I_p$  flows through resistance  $R$ , you get a voltage drop which varies directly as  $I_p$  varies. The GAIN, or voltage amplification, of the tube is the ratio of this voltage variation,  $E_o$  across  $R$  to the input signal voltage,  $E_s$ . Or—

$$\begin{aligned}\text{Voltage gain} &= \frac{E_o}{E_s} \\ &= \frac{\text{Amplification factor} \times \text{load resistance}}{\text{Load resistance} + \text{plate resistance}} \\ &= \frac{\mu R_L}{R_L + R_p}\end{aligned}$$

From this, you can see that the net gain of the tube is less than  $\mu$ . But if you make the load resistance large compared to the tube resistance, you'll make the gain come close to the value of  $\mu$ .

In figure 98, you can see how increases in load resistance increase the  $\mu$  of the tube. If you want high gain from a voltage amplifier tube, run the load resistance up. And here's how to do that—

In a resistance-coupled amplifier, the  $R_L$  of the tube is approximately equal to the resistance of the plate resistor in parallel with the grid resistor of

the next stage of amplification. So, to get a large value for  $R_L$  you use a plate resistor and grid resistor of large values. But—

Don't make the plate RESISTOR too LARGE, or the plate VOLTAGE will be too SMALL. You see, the flow

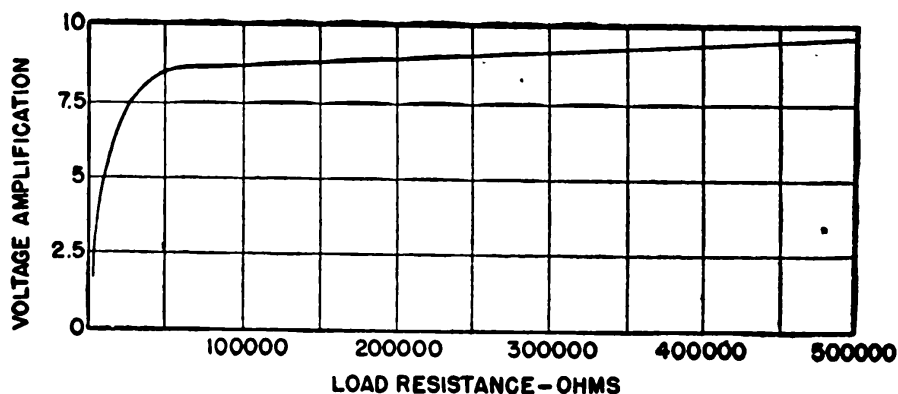


Figure 98.—Curve of  $\mu$  vs.  $R_L$ .

of plate current  $I_p$  through this resistor causes a voltage drop which lowers the plate voltage  $E_p$  across the tube. If  $R_p$  is high, the  $IR$  drop will be high, the plate voltage  $E_p$  will be too small, and you'll get a low voltage output from the amplifier tube. Also—

Don't make the grid resistor of the next stage too large. The charts in tube manuals usually tell you what size resistor to use in the stage following a certain type of tube.

You can use a larger grid resistor when you're using cathode bias than when you're using fixed bias. The LOSS in bias due to grid emission effect when using cathode bias is usually offset by the INCREASE in bias due to voltage drop across the plate resistor.

### INPUT IMPEDANCE

The INPUT IMPEDANCE of a vacuum tube is the total impedance between the grid and cathode. It consists of three parts—the capacitance between grid

and cathode, a resistance produced by the time the electrons take to travel from cathode to grid, and a resistance caused by using part of the cathode lead for both input and output circuits. The frequency of the input signal determines the size of the two latter parts of this input impedance.

If you put negative grid bias on a tube operating at a.f., the input impedance will be high. But at r.f., the input impedance may drop very low, even with negative grid bias, on account of the length of time electrons take to travel from cathode to grid, and on account of the measurable cathode lead reactance. This input impedance drops very fast as you increase the frequency, and raises the input circuit loading. In fact, the input impedance may drop low enough at very high r.f. to seriously affect the gain and selectivity of a preceding stage of amplification.

The "acorn" type tubes were developed to have low input capacitances, low electron-transit time, and low lead inductance. These tubes have high input impedance even at the ultra-high r.f.'s.

## COUPLINGS

You'll find three types of couplings used between radio amplifier stages. They are—inductive or TRANSFORMER, impedance or CHOKE, and RESISTANCE. You'll run into RESISTANCE coupling more often than the other two, since it is usually used in class A amplifiers. It saves space, costs less, and gives a more uniform response or amplification on a.f.

### RESISTANCE-COUPLED AMPLIFIERS

If your amplifier has a RESISTANCE LOAD, it is a RESISTANCE-COUPLED AMPLIFIER. This type is used a lot for audio-frequency amplification, and a circuit is shown in figure 99. Here the resistance-coupled amplifier feeds to the following tube.

All the power output of resistance-coupled amplifiers is used up in the load resistor. Therefore, you use this type of amplifier almost solely for voltage amplification, usually feeding into another amplifier.

The COUPLING CONDENSER  $C_4$  in figure 99 transfers the a-c voltage developed across  $R_3$  over to the grid of the right-hand triode. The coupling condenser also prevents the d-c plate voltage on the left-hand triode from feeding over to the grid of the second triode.

You use grid resistor  $R_4$  to transfer the BIAS VOLTAGE to the grid of the second tube. This resistor also prevents short-circuiting the a-c voltage through the

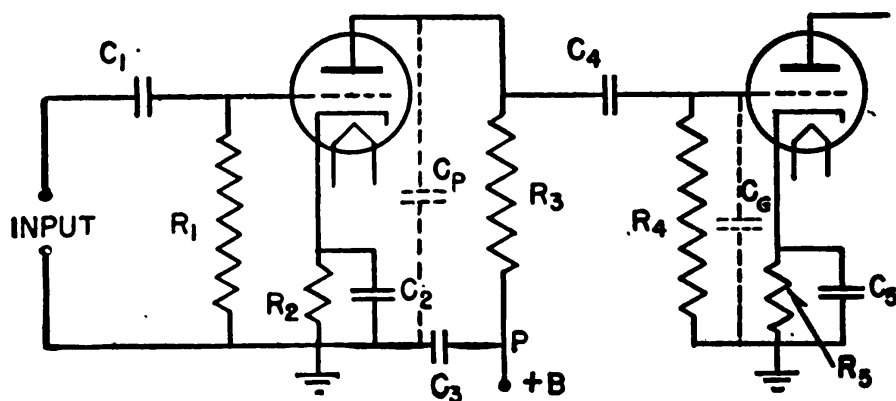


Figure 99.—Resistance-coupled amplifier circuit.

bias battery. You have no grid current flowing, hence there is no d-c voltage drop in  $R_4$ , and the full bias voltage is applied to the grid.

Make the reactance of  $C_4$  SMALL compared to the resistance of  $R_4$ , so that most of the voltage will be across  $R_4$ , rather than across  $C_4$ . Then you will get the maximum a-c voltage at the grid of the second tube. AND, the resistance of  $R_4$  must be LARGE compared to  $R_3$ , since  $R_4$  and  $R_3$  ACT in parallel as regards their EFFECT on the a-c voltage developed in  $R_3$ . BUT, if you make  $R_4$  TOO LARGE, stray electrons that collect on the grid may not leak off back to the cathode fast

enough to prevent them from piling up on the grid. This increases the negative grid bias, and shifts the tube operating point. You usually select  $R_4$  with a value between 0.5 and 2 megohms. And  $R_s$  is usually about 0.1 megohm for a triode.

In the MIDDLE-FREQUENCIES, you can find GAIN by this formula—

$$\text{Gain} = \mu \frac{R}{R + R_p}$$

where  $R$  is the parallel resistance of the plate load and the grid resistance, or

$$R = \frac{R_L R_{GL}}{R_L + R_{GL}}$$

Here you ignore the capacities of  $C_p$  and  $C_g$ , which are quite small, and the resistance of  $C_4$  has no effect.

Here, then are the important points to a resistance-coupled amplifier circuit—

Make the grid leak  $R_{GL}$  as large as you can without letting the SMALL grid current that flows as a result of electrons hitting the grid to build up to any large bias voltage.

Load resistance  $R_4$  should be large compared to the plate resistance.

Choose COUPLING CONDENSER  $C_4$  to have a reactance about half the resistance of the grid leak at the lowest frequency to be transmitted. Then the gain will remain at about 90 percent of the middle-frequency gain. But—

Don't make  $C_4$  too large, or you'll develop low-frequency oscillations or "MOTORBOATING."

### TRANSFORMER-COUPLED AMPLIFIERS

To make a TRANSFORMER-COUPLED AMPLIFIER, you connect the primary  $T_s$  of a transformer to the plate of a tube, as in figure 100A. This coupling introduces only a very small d-c resistance in the grid



circuit of the second tube  $V_2$  to which the amplified voltage is delivered. This coupling also works better with push-pull circuits than the resistance-coupled amplifier.

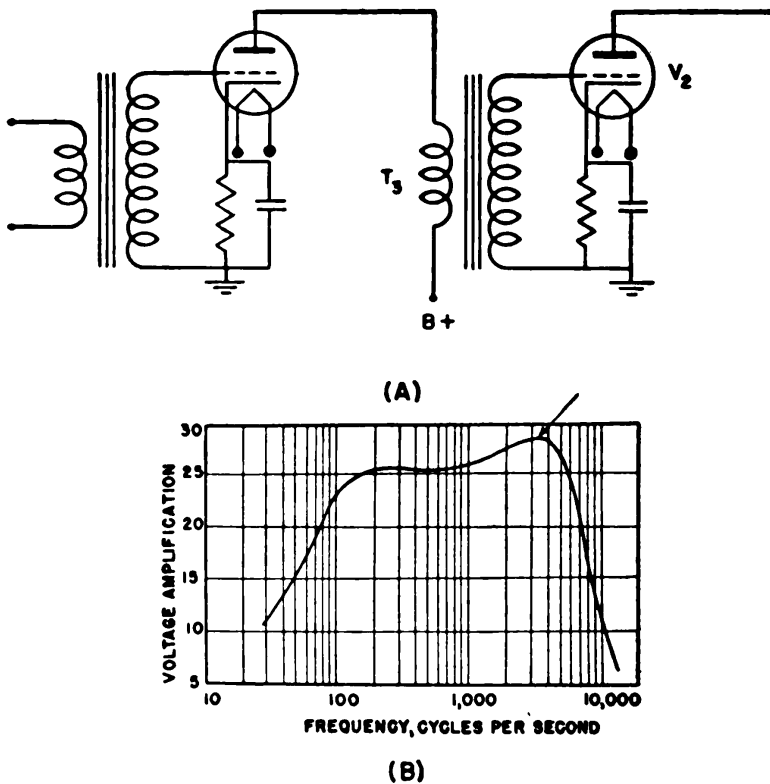


Figure 100.—Transformer-coupled amplifier.

A transformer-coupled amplifier gives you an amplification curve, figure 100B, that is relatively constant in the middle frequencies, and falls off at the low and high frequencies. The low-frequency drop is caused by the low reactance of the transformer primary  $T_1$  at low frequencies, while the loss at high frequencies is the result of leakage inductance and effective secondary capacitance of the transformer. BUT—

You can readily design the transformer coupling to provide a useful voltage amplification across the voice frequency range. However, when you try to

use transformer coupling for low and high frequencies, you hit trouble. Instead, use resistance coupling where you have to cover very wide bands.

Also, the transformer has a tendency to RESONATE at one frequency, giving you an amplification PEAK such as you see at 3,500 cycles on the curve of figure 100B. This peak gives you a certain amount of FREQUENCY DISTORTION. You can reduce this peak by putting a resistance of between 0.25 and 1 megohm across the transformer secondary. But this reduces the amplification at medium and low frequencies, even though it keeps the frequency response curve from peaking.

Transformer-coupled amplifiers usually use triodes having low or medium  $\mu$ , and medium plate resistance. Here's why—the primary inductance needed to give good amplification at low frequencies is proportional to the plate resistance of the tube. Actually, you'll have trouble getting high primary inductance, a large ratio of secondary-to-primary turns, AND low distributed windings capacity all at once. And, if you increase the PRIMARY INDUCTANCE, usually you must cut down the turns ratio. This reduces the secondary inductance to compensate for the increased capacity. Otherwise, the increase in capacity of larger coils tends to move the RESONANT PEAK back to a relatively middle-frequency point on the band.

You can use transformer coupling at RADIO frequencies if you design the transformer to have a resonant primary OR secondary at the frequency to be used. Thus, you obtain maximum amplification.

Disadvantages of transformer coupling—  
COSTS MORE than resistance coupling.

The STRAY MAGNETIC FIELDS in the transformer tend to cause stray voltages to be induced in the secondary.

## PUSH-PULL AMPLIFIERS

You can increase the power output of an amplifier unit by connecting two tubes in PUSH-PULL. You connect the grids and plates of the tubes to opposite ends of the circuit, as in figure 101.

Here are the advantages of push-pull—

You produce NO D-C SATURATION in the output transformer core. Hence, increase in inductance is higher, and you get better low-frequency response.

There's no signal-frequency current through the plate-power source. Hence, you get NO REGENERA-

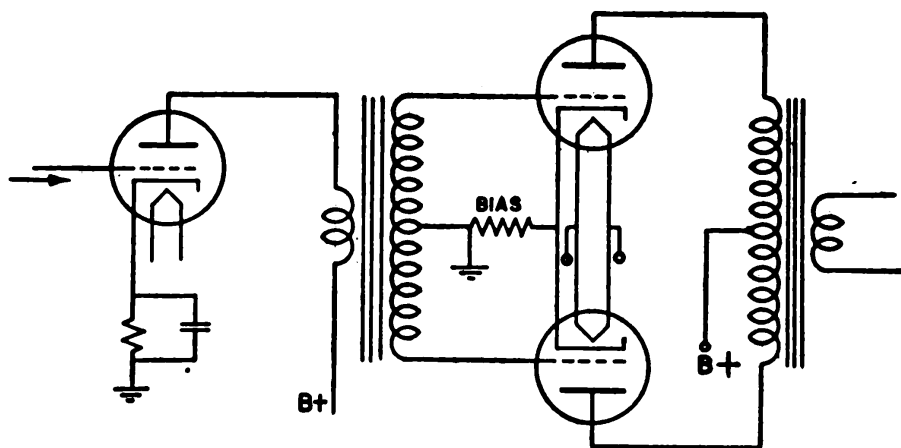


Figure 101.—Push-pull amplifier circuits.

TION from a push-pull amplifier even when you have plate impedance that is common to the power stage and other stages.

LESS HUM EFFECT is produced by a-c voltages in the plate-power source. The hum currents flowing in the two halves of the primary cancel out each other.

LESS DISTORTION, or MORE power, per tube.

All these advantages are so important that you'll be better off to use TWO small tubes in push-pull, rather than use one large tube capable of developing equal power in ordinary amplifier circuits.

Figure 102 shows you curves of individual and combined output for a push-pull circuit such as was diagrammed in figure 101. From these curves, you see that push-pull makes the positive and negative halves of the output wave have the same shape, even though the outputs of the tubes separately would not

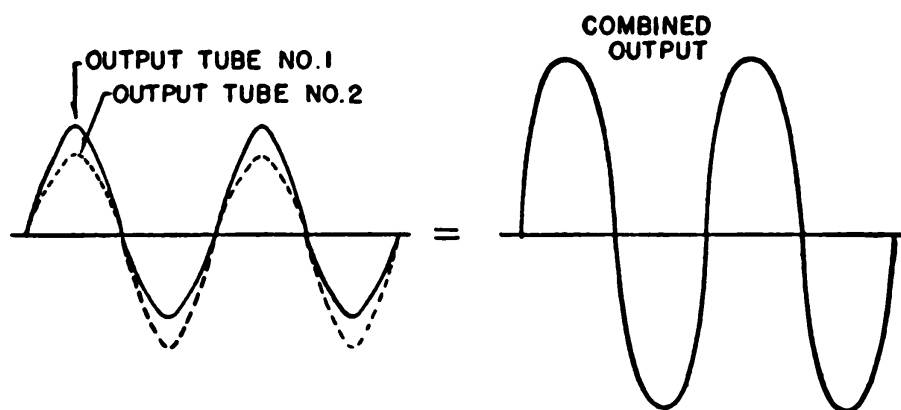


Figure 102.—Output of push-pull amplifier.

produce identical plus and minus loops. Result—the output wave contains NO EVEN HARMONICS—2, 4, 6—hence, suffers LESS DISTORTION than would the outputs of the two tubes separately. Class AB audio amplifiers are used only in push-pull.

### TRANSFORMER-COUPLED PUSH-PULL

Back in figure 101, TRANSFORMER COUPLING AND PUSH-PULL are used to extend amplifier operations into regions where you'd normally get distortion with single-tube amplifiers.

You use a center tap on the primary of the output transformer. This transformer should have a turns-ratio that will give you a plate-to-plate impedance on the primary that is equal to TWICE the load impedance of a comparable single-tube power amplifier. See why? As far as output is concerned, the two tubes of the push-pull ACT in series.

## IMPEDANCE-COUPLED AMPLIFIERS

If you replace either the plate resistor or grid resistance-coupled amplifier with an inductance, you'll have an IMPEDANCE-COUPLED, as in figure 103. Note the similarity between the circuits of figures 103 and 99.

The advantage of the impedance-coupled amplifier is the low  $IR$  drop in the plate-load winding  $Z_1$ , as compared with the  $IR$  drop in a resistance coupling.

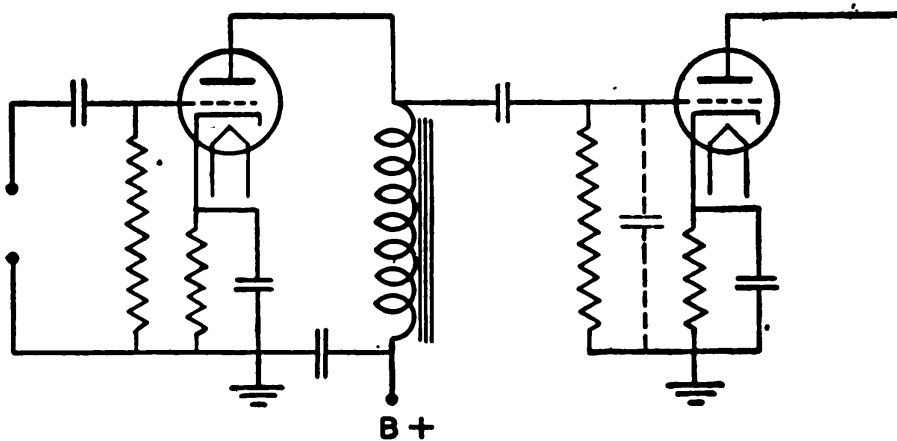


Figure 103.—Impedance coupling.

The high voltages that can be developed across  $Z_1$ , due to its reactance, are also advantageous. But—

One disadvantage is the ability of the impedance-coupled amplifier to develop induced emfs in the plate reactor windings  $Z_1$ . These emfs will cause distortion and noises in the output. Another disadvantage is the limited frequency response of this type of amplifier at both ends of the frequency band. At very LOW frequencies the drop-off is caused by the decreasing reactance of the coil, and at very high frequencies, the reactance of the shunt capacities drops, causing response to drop.

This type of coupling can also be used at radio frequencies, since you can adjust the inductance to

RESONATE with the shunt capacities at almost any frequency.

## MOTORBOATING

MOTORBOATING has nothing to do with boats or motors—it's a term to describe the low-toned "put-put-put" that comes out of your loudspeaker when the amplifier starts to oscillate. Motorboating occurs when you have stray couplings somewhere in the amplifier circuit, and one of them is a coupling between stages through a common voltage supply circuit.

You use filters to cut down the trouble from these stray couplings. Put the filters in the voltage-supply leads to each tube. Then the signal currents will have a direct low-impedance path to return to the tube cathode, and they won't stray into the voltage supply circuit. The diagram of figure 103 gives you several anti-motorboating filter circuits. The condenser *C* supplies the low-impedance path, while the choke or resistor *R* is the high-impedance path in the power-supply circuit to direct the signal through the condenser circuit.

Whether you use a resistor or a choke depends upon the d-c voltage drop you can afford to take across the filter. In circuits where you have a small current, you can use resistors. In circuits handling large currents or where good regulation is important you'll need chokes.

Here's a good rule for estimating the minimum size of condenser you can use—

At the LOWEST frequency you are amplifying, your CONDENSER IMPEDANCE should be LESS than ONE-FIFTH of the impedance of the FILTER CHOKE or resistor at that lowest frequency. In some cases, you'll get better results by holding condenser impedance below ONE-TENTH.

Because of the 180-degree phase inversion in a

tube circuit, motorboating occurs when the alternate stages—one, three, and so on—are coupled. Thus, voltage fluctuations in the third amplifier plate circuit will be in phase with the fluctuations in the first-stage plate circuit. Result—you get regeneration and motorboating.

You can even get DEGENERATION if your impedances are connected between adjacent stages, since the coupled variations are  $180^\circ$  out of phase. Degeneration cuts down amplification, so you should avoid it by using filters in ALL plate and screen circuits. Filters are good protection against either REGENERATION or DEGENERATION.

Occasionally, even filters fail to clean up the motorboating in a low-frequency, high gain amplifier. Then you have to use separate power supplies for various parts of the amplifier.

### CLASS "A" POWER AMPLIFIERS

You're an expert now on class A VOLTAGE amplifiers, so take a look next at class A POWER amplifiers.

You'll find a radio tube being used in the output stage of radio receivers to supply large amounts of POWER to operate the loudspeaker. Here power is of much more importance than voltage gain, so power tubes are designed for maximum power amplification with almost no effort to develop voltage amplification too.

Triode power tubes in class A service provide low power sensitivity, low plate power efficiency, and low distortion. Pentodes have high power sensitivity, high plate power efficiency, but high distortion. And beam-power tubes have still higher power sensitivity and efficiency and higher power output than either triodes or ordinary pentodes.

You can use a class A power amplifier as a driver to supply power to either a class B or a class AB output stage. Because of the lower distortion of a triode,

you usually use this type of tube as a driver, rather than a pentode.

In figure 104*A*, you see the circuit for a PARALLEL connection of power tubes to obtain increased power output for class A amplifier. You could also use the PUSH-PULL connection of figure 104*B*, but

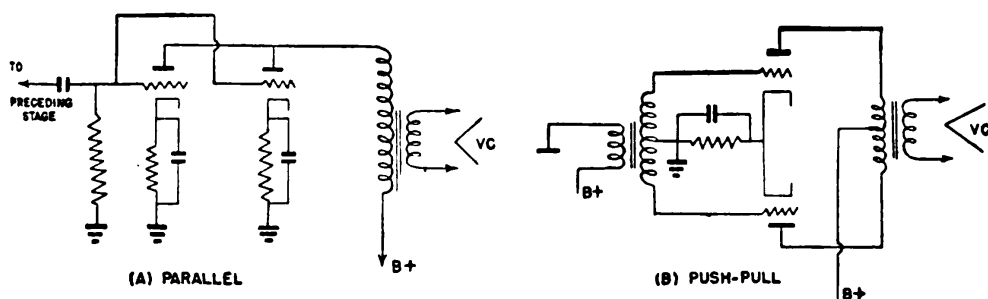


Figure 104.—Parallel-connected power tubes.

this one requires twice the input original voltage. However, the PUSH-PULL has these advantages over single-tube operation—

You either eliminate or greatly reduce distortion due to even-order harmonics, and hum caused by plate-supply voltage fluctuations.

You can get more than twice the single-tube output with push-pull by reducing the load resistance, since push-pull distortion is less.

If the push-pull or parallel stages start oscillating, you can often eliminate the oscillations by putting a 500-ohm non-inductive resistor in series with each grid lead at the tube socket.

## CLASS "B" POWER AMPLIFIERS

The class B power amplifier uses two tubes in push-pull, and biased so that the plate current is practically ZERO when no signal voltage is on the grid. Because of this low value of zero-signal plate current, large power output can be obtained without excessive plate current dissipation. The plate cur-



rent in B is cut off for a larger part of the negative grid swing.

Several tubes have been designed with high  $\mu$  especially for use with class B amplifiers. With high  $\mu$ , plate current is small when grid voltage is zero, and these tubes can operate in class B at a bias of ZERO volts. No bias supply is necessary. Frequently class B tubes are made up of two triodes mounted in one glass or metal envelope, and two triodes can be connected in push-pull so that only one tube is needed for each stage.

Since you operate a class B stage at zero bias, each grid has a positive potential during the positive half of its swing. And a large grid current flows, causing a power loss in the grid circuit. So, your driver stage must be able to supply considerably more power than is required for the grid circuit in order to avoid serious distortion. The inter-stage transformer between the driver and the class B stage is usually a step-down transformer.

Plate current fluctuations in the class B are large, so you need good regulation of the power supply.

### PHASE INVERSION

The signal-voltage inputs to the grids of a push-pull stage must be  $180^\circ$  out of phase, and about equal in amplitude. So you use a PHASE INVERTER to put in RESISTANCE COUPLING between the output of a single-tube stage and the input of a push-pull stage. You see a phase-inverter circuit in figure 105.

When the signal input to the push-pull stage swings the control grid of one tube positive, the same input swings the control grid of the other tube negative by the same amount. If you use TRANSFORMER coupling between stages, you supply the out-of-phase input voltage to the push-pull stage by means of the center-tapped secondary. But with RESISTANCE COUPLING,

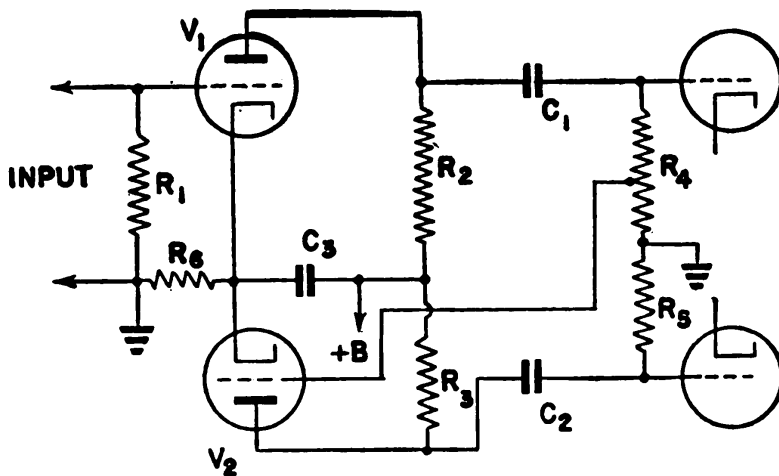


Figure 105.—Phase inverter.

you get the out-of-phase input voltage by using the inverter action of the tube.

In the circuit of figure 105, phase inversion is supplied by triode  $V_2$ .

### INVERSE FEEDBACK

You'll sometimes hear an INVERSE FEEDBACK CIRCUIT called a DEGENERATIVE CIRCUIT, since a portion of the output voltage of a tube is fed back to the input of that same tube or a preceding stage, as in figure 106. This feedback is in OPPOSITE phase to the signal applied to the tube.

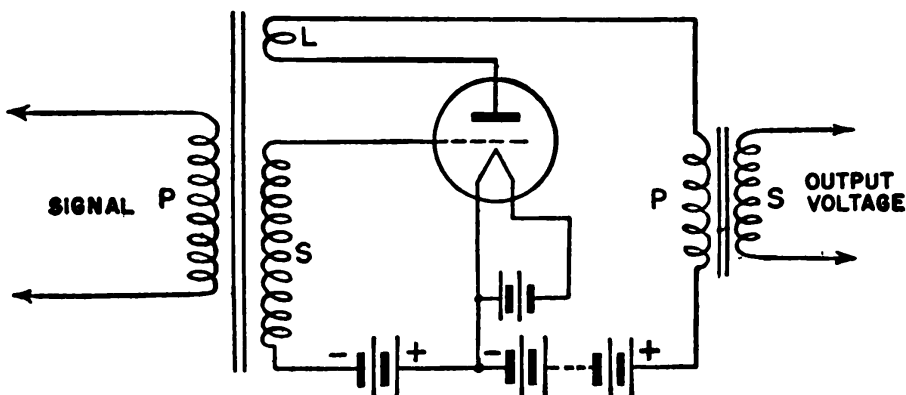


Figure 106.—Inverse feedback.

Here's why you use inverse feedback—

It cuts down DISTORTION from each stage that is included in the feedback circuit.

It cuts down GAIN VARIATIONS due to changes in line voltage, slight differences in tubes of the same type, or variations in the values of circuit constants included in the feedback circuit. You usually use inverse feedback in a-f amplifiers to reduce distortion in the output stage where the load impedance is not constant, as, for example, with a loudspeaker. Also, if you are using a tube with high plate resistance, such as a pentode or beam-power tube, you use inverse feedback to reduce the distortion caused by the varying plate-load impedance.

But inverse feedback cuts down the amplitude of the output current, as well as reducing distortion. So you must pull the power output up to full value by increasing the signal voltage. This calls for more driving voltage to get full signal voltage. But you'll get less distortion with inverse feedback at the higher voltage.

### TONE CONTROL

On most amplifiers you find a TONE CONTROL that lets you choose between the various audio frequen-

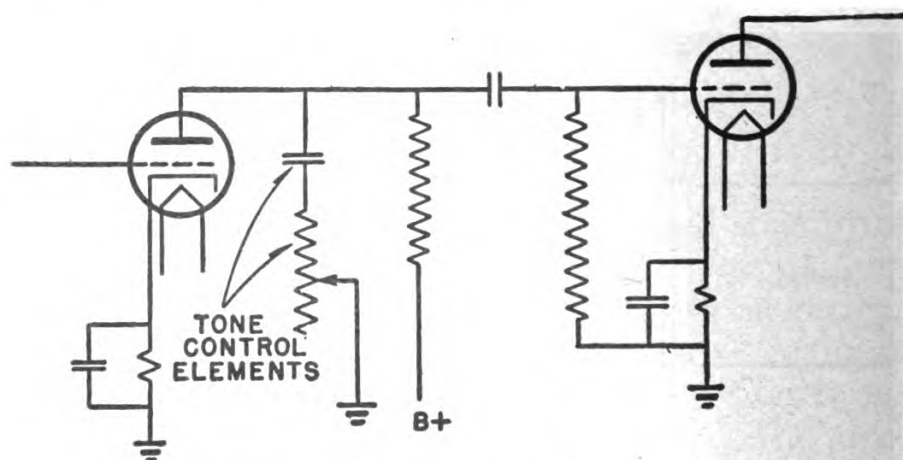


Figure 107.—Tone control circuit.

cies. The tone control simply by-passes the high frequencies to ground. You can reduce much of the hiss and crackle in an amplifier without disturbing the intelligibility of the signals.

In figure 107, you have the circuit of a tone control.  $R$  and  $C$  together form the tone control circuit, and give maximum effect when resistance  $R$  is entirely out of the circuit, leaving only  $C$  connected directly between the grid and ground. Make  $R$  large compared to the reactance of  $C$ , so that when all of  $R$  is IN the circuit the effect of  $C$  on the frequency response will be of no importance.

### OUTPUT COUPLING

But your signal still hasn't been put into a form that the loudspeaker can transform into AUDIBLE waves. And this brings up OUTPUT COUPLING.

In code receivers, you are more interested in keeping the gear simple and easy to maintain than you are in the fidelity of the output signal. But the audio stage of an amplifier requires high fidelity. So you are much interested in frequency response and output coupling.

Normally, the dynamic speaker to which you connect your amplifier output has an impedance that is different from what you'd use as a plate load for the output stage. So you'll need to use an IMPEDANCE-MATCHING DEVICE of some sort—usually a TRANSFORMER.

By using a transformer, you avoid running the d-c plate current through the load impedance. Also, you choose the proper turns-ratio to make any load supply the proper impedance to the tube. But—

Inductance in the primary causes the amplifier output to drop off at both high and low frequencies. Also, leakage inductance increases the drop-off at high frequencies.

## SHUNT FEED

The SHUNT FEED arrangement of figure 108 is often used to avoid running the d-c plate current through the transformer primary. You avoid d-c saturation of the core, and thus increase the inductance in the primary. You can also reduce the wire size of the transformer primary.

By using shunt feed, you can improve the fre-

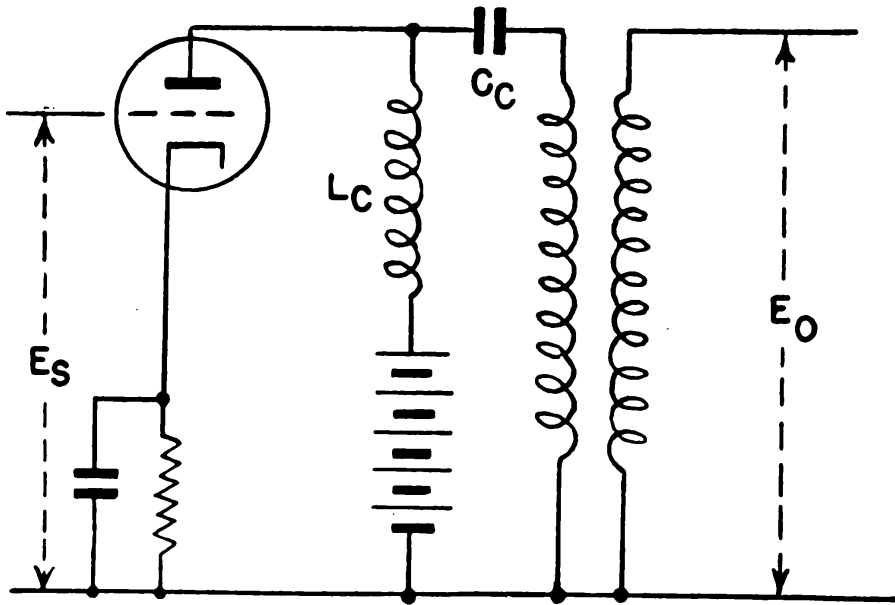


Figure 108.—Shunt feed.

quence response greatly, and when using large tubes you reduce the cost of obtaining a specific response characteristic. Shunt feed adds nothing to the leakage, hence can be made large enough in size to provide a high increment of inductance. At the same time, you take the d-c out of the transformer primary, and can reduce the air-gap of the transformer core. This increases the primary inductance without increasing the leakage, and allows you to secure a given primary inductance with smaller leakage inductance.

You must use shunt feed with all transformers that have high-permeability alloy cores. The incremental

permeability of all such cores is greatly reduced with d-c magnetization of any size.

### DISTORTION

If your amplifier were perfect, it would give output waves that precisely duplicated the input waves in everything except amplitude. But an amplifier

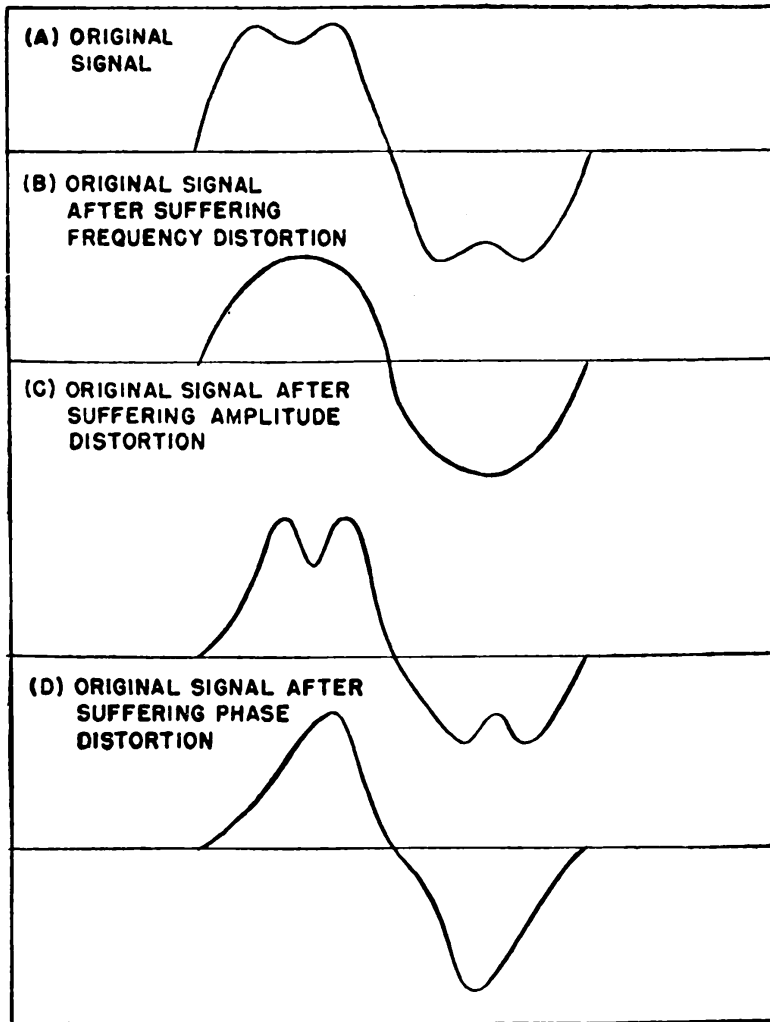


Figure 109.—Various kinds of amplifier distortion.

CAN be imperfect in one or more of three ways. It can cause FREQUENCY DISTORTION by failing to amplify all the various frequency components of the input voltage equally well. Or it can cause AMPLITUDE, or NON-LINEAR, distortion by supplying an

output that is not exactly proportional to the amplitude of the input. Or it can produce PHASE DISTORTION by throwing the relative phases of the various output waves out of kilter with the phases of the input waves. These three types of distortion are illustrated in figure 109.

### FREQUENCY DISTORTION

FREQUENCY DISTORTION results in amplifying certain selective frequencies more than it does others. In other words, the amplifier has a greater gain on certain frequencies than others.

Frequency distortion limits the range of frequencies that your amplifier can handle, and is of great importance in amplifier design, especially audio and video amplifiers. Frequently distortion is increasingly hard to remove as the width of the frequency bands increases. And you'll find more frequency distortion as the amplification per stage increases. If you want to keep frequency distortion low, you must make some sacrifices in amplification. You see frequency distortion in figure 109B.

### NON-LINEAR DISTORTION

NON-LINEAR DISTORTION is caused by the vacuum tube operating on the non-linear portion of the characteristic curve. It results in the  $\mu$  of the tube being less on the negative cycle of the signal than it is on the positive cycle of the signal. Non-linear distortion limits the practical output voltage of current from the amplifier by putting frequency components into the output waves that weren't in the input voltage to the grid. In figure 109C you see an example of non-linear distortion.

The most important non-linear distortion frequencies are harmonics of the frequencies in the input, and sum-and-difference frequencies formed by signal voltage components.

## PHASE DISTORTION

You can get PHASE DISTORTION when the different frequencies that make up the input wave are not passed through the amplifier in the same interval of time. The wave form changes, but the magnitude may not. The wave in figure 109*D* has been PHASE-DISTORTED. Compare it with the original in figure 109*A*, and you'll see that the shape of the two waves are quite different in shape, even though the output contains the same frequency components and has the same relative amplitude as the input wave.

Practically phase distortion in most a.f. amplifiers is fairly unimportant, since the phases can be varied over a wide range without producing an effect on the human ear. Only when the time of transmission is about as long as the duration of the signal voltage applied do you have to consider phase distortion. You'd run into this condition only in television circuits and long-line telephone and telegraph circuits.

## NOISE, HUM, AND MICROPHONIC ACTION

Every amplifier has SOME output, even when there is no input voltage. This output may be called HUM, NOISE, or MICROPHONIC ACTION, depending upon its origin.

### HUM

You'll get HUM in any amplifier when 60-cycle a-c lines run close to the amplifier. Hum is especially bothersome in high-amplification a.f. amplifiers, since hum introduced in the early stages will be greatly amplified by following stages.

In r.f. amplifiers, hum is less troublesome, but cannot be ignored. Even though the induced hum voltages are not amplified, they put voltages on the tubes that can vary the amplification of the r.f. signals. Hence the hum may modulate the r.f. being amplified.



An amplifier may pick up hum from STRAY MAGNETIC FIELDS, STRAY ELECTROSTATIC FIELDS, A.C. in the filament or the heater of the tube, or IMPROPERLY FILTERED POWER supply. You can avoid hum from improperly-filtered power by properly designing the power supply. Proper choice of tubes will prevent the pick-up of hum from the a-c filament heater. The only hum that presents a tough problem of removal is that caused by stray MAGNETIC and ELECTROSTATIC FIELDS.

Here's what MAGNETIC FIELDS do to cause trouble—

They induce voltages in interstage coils, input a-f transformer coils, and other coils. They induce voltages in wires that are accidentally or carelessly arranged in LOOPS. They may even affect the flow of electrons between the cathode and plate of the tube.

Around an amplifier, you may get MAGNETIC FIELDS from the power transformer, the leads that carry the filament or heater currents of the tubes, and the filter chokes. You can get rid of the trouble from the tube leads by twisting them together, or by changing their path. You can eliminate stray fields from power transformers and filter chokes by turning them in the most satisfactory direction, by leaving lots of space between them and the first stage amplifier, and by selecting transformers and chokes that have low leakage flux.

And here's how ELECTROSTATIC FIELDS cause trouble—

In parts of the amplifier that have a high impedance to ground, the electrostatically-induced currents flowing to ground will produce a hum voltage that is proportional to the impedance between the circuit and the ground. Especially when the grid of an a-f amplifier is left disconnected or is grounded through a very high resistance, the impedance between grid and ground will be so high that a VERY large hum voltage will be developed

between grid and ground by the electrostatic fields of nearby lighting circuits.

To avoid trouble from electrostatic fields, you enclose the tubes in metal shields, and you either make the grid leads very short or shield them. In an a-f amplifier having very high gain, you enclose the first stage or two in a metal box so that the WHOLE input circuit is shielded.

You must ground the chassis of high-gain amplifiers to first-rate grounds, unless you have electrostatic shields on all power, filament, input, and output transformers.

And here's a really tough HUM problem—the hum in a-f amplifiers caused by voltages in transformers used with the first amplifier stages—particularly the input stage. The signal being amplified in these first stages is quite small, hence very little hum voltage can be about equal to the signal. RESISTANCE COUPLING throughout is the answer to this problem. And dispense with an input transformer to the first amplifier stage, even though it means a considerable reduction in amplification. Use DIRECT COUPLING, instead.

If you MUST use an input transformer, keep it as far away as possible from the power transformer. Also turn it around and move it until you find by trial-and-error the spot where it causes the least hum pickup. And shield it magnetically using either a cast-iron housing or a heat-treated permalloy or a heavy copper shielding around the input transformer.

And if everything mentioned fails to keep out the hum, you can put the input transformer and first amplifier stage or two in a separate unit some distance from the power transformer, and connected by cables.

### MICROPHONIC ACTION

If you jar a tube, the electrodes will vibrate, causing MICROPHONIC ACTION. In an a-f amplifier, this

action will cause changes in the plate current that are of audible frequency and that are amplified along with the desired signal.

In an r-f amplifier, the microphonic action varies the amplification somewhat, and causes the microphonic noises to be modulated upon the r-f signal.

Here's where microphonic action gets started—

The tubes can pick up either mechanical vibrations caused by shaking, jarring, or neighboring vibration, or acoustical vibrations caused by a nearby loudspeaker. For example, an airborne amplifier could be jolted by bumpy weather, or could be vibrated by the vibration of the aircraft engines. The loudspeaker on a home radio could be installed so that the musical or speech vibrations of the loudspeaker would strike the amplifier tubes, and set up microphonic action.

You can reduce the effect of microphonic noises by mounting the tube socket on springs or rubber cushions, and by protecting the tube from loudspeaker vibrations.

Also, some tubes of the same type differ widely in structure and the tendency to cause microphonic action. When you run into microphonic noises, try replacing the tubes in the first amplifier stage until you get one that is least affected by vibration. If this doesn't correct the trouble, you'll have to put in different types of special non-microphonic tubes that are designed with extra-rigid internal structure to resist vibration.

NOISE is the name for the various crackling, sputtering, and frying sounds which have no regular pitch. NOISE is caused by poor contacts, faulty resistances, failing condensers, and discharged batteries.

You'll find that carbon resistors carrying d.c. are especially bad noise-producers. You cannot use them as plate-coupling resistances if they are to be followed

by more than one stage of a-f amplification. The noise is caused by fluctuations in the contact resistance between the carbon granules. The noise voltage is roughly proportional to  $IR$ .

But even after you've got rid of all the possible sources of noise, you'll still find a little noise kicking around. It's caused by THERMAL AGITATION OF ELECTRONS, by SHOT EFFECT, and similar phenomena. It is a frying, hissing noise that represents energy lost across the entire frequency band.

The most important source of noise in a properly-operated amplifier is the THERMAL AGITATION of electrons in the input circuit conductors. You remember the electron theory. Electrons are continually moving around in metals and at a rate dependent on the temperature of the metal. Since more electrons will generally be moving in one direction than in the other, you'll develop a voltage across the conductors. This voltage won't be steady, but will vary from instant to instant in an irregular manner according to the motion of the electrons. The square of this voltage across the impedance is directly proportional to the resistance component and the temperature of the impedance. The energy developed is uniformly spread across the whole frequency band from zero frequency up to frequencies far above those used in radio.

Thermal-agitation noise voltages put a limit to the lowest signal voltage you can amplify without losing the signal in a background of noise. The NOISE LEVEL of most amplifiers is determined by the thermal agitation of the resistance in the first-stage amplifier tube. But, if this resistance is quite low, you may use the thermal agitation in the plate resistance and plate load impedance of the first tube as the limiting factor.

## SHOT EFFECT

SHOT EFFECT is caused by the stream of electrons or PARTICLES that are fired from cathode to plate. These electrons strike the plate much as a stream of shot or pebbles poured out of a bucket would strike a tin pan. Each electron striking the plate produces a tiny momentary change in voltage. This causes irregularities in the plate current, and produces noise in the amplifier.

The SPACE CHARGE around the cathode acts as a cushion to smooth out the flow of electrons that go to the plate, and thus avoid the shot effect when full temperature saturation exists in the tube. That's why you must have tubes that give out a full electron emission at the cathode to insure a sufficient space charge. Then noise from shot effect will be held to a minimum.

Shot effect represents a distribution of energy all across the frequency range, just as did thermal agitation.

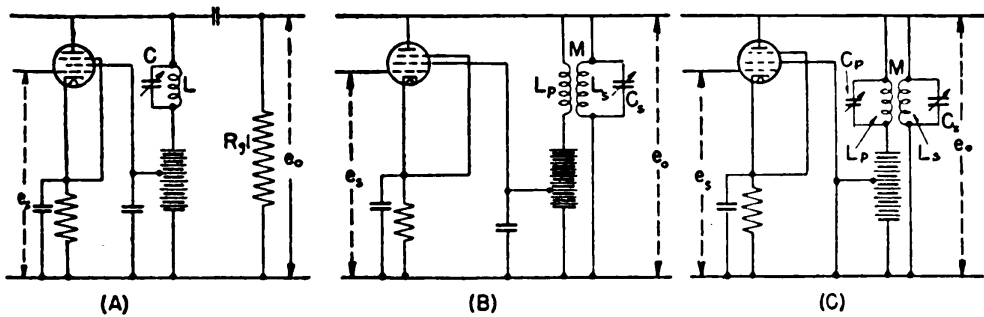
There are also OTHER noises—FLICKER EFFECT and IONIZATION.

FLICKER EFFECT is a modified type of SHOT EFFECT, and is caused by irregular changes in emission at local areas on the cathode. Flicker effect is worst with oxide-coated cathodes, where it is usually a far greater nuisance than true shot effect.

The other noise-producer is IONIZATION, caused by the production of POSITIVE IONS within the vacuum tube. These positive ions can be produced either by ionization of the little bit of gas left in the vacuum tube after evacuation, or by the emission of positive ions by the cathode, especially tungsten cathodes. These positive ions cause SHOT EFFECT by upsetting the normal space-charge balance. A tube having a high vacuum will have an ionization noise level about equal to the thermal-agitation noise level.

## TUNED-VOLTAGE AMPLIFIERS

In a tuned amplifier, you supply the load impedance by means of a resonant circuit, using resonance in parallel to get the required high impedance. Amplifiers of this type are usually used on radio-frequencies. They work well because they make use of the stray and tube capacities to help tune the resonant circuits. They also provide good frequency selectivity, giving an amplification that varies with frequency much as do the responses of an ordinary resonance curve. Thus, you can amplify signals of the desired frequency and eliminate the unwanted signals.



DIRECT-COUPLED TRANSFORMER-COUPLED BAND-PASS COUPLED  
Figure 110.—Typical tuned-amplifier circuits.

In tuned r-f voltage amplifiers, you usually use pentodes that have the control grid fully shielded from the plate circuit. Tubes of this design are usually called RADIO-FREQUENCY PENTODES. They give greater gain than triodes, and have negligible capacitance coupling between the plate and grid circuits. Screen-grid tubes are better than triodes, but not as satisfactory as r-f pentodes.

Figure 110 shows diagrams for several typical tuned-amplifier circuits. Basically the principles of operation for each are similar, the main difference being the methods of coupling the tuned circuit to the plate circuit of the amplifier tube. You can analyze each of these circuits by using equivalent circuits.

## DIRECT COUPLING

The DIRECT-COUPLED circuit of figure 110*A* is the simplest form of tuned-amplifier circuit.

You will see that the stray wiring capacities and the plate-cathode capacity of the amplifier tube, and also the grid-cathode capacity of the tube to which the output voltage is delivered, help tune the circuit, and therefore, do no noticeable harm.

Figure 111 gives you the results around the reso-

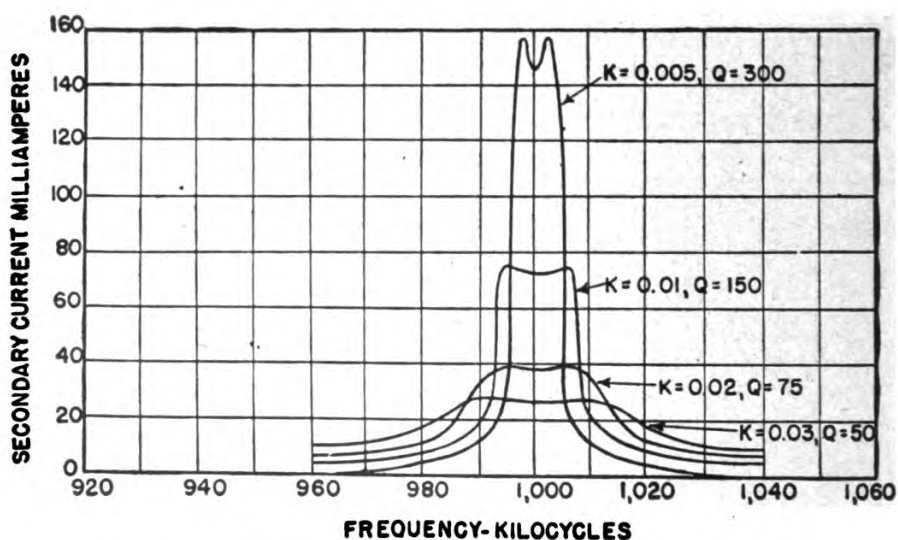


Figure 111.—How amplification varies with frequency in a tuned amplifier.

nant frequency. You will see by looking at the illustration and at the amplification equation that the amplification curve and a resonance curve are similar in shape. The maximum amplification takes place at the frequency at which the tuned circuit is resonant if the parallel impedance of this circuit at this frequency is  $\mu L Q$ . You recall that  $Q$  is the ratio of coil reactance to coil resistance, or

$$Q = \frac{\mu L}{R}$$

Since the grid-leak resistance and plate resistance are both much higher than the parallel impedance

of a resonant circuit having normal proportions, you'll get close enough to an approximation of the formula for amplification at resonance by making

$$\text{APPROXIMATE Amplification at Resonance} = G_m \mu L Q.$$

Lay out the amplification curve as a function of frequency. You'll find that its shape fits that of a curve of lower  $Q$  than the actual  $Q$  of the resonant circuit. The grid-leak and plate resistances of the tuned circuit determine the ratio of EFFECTIVE  $Q$  of the amplification curve to the ACTUAL  $Q$  of the tuned circuit. Or

$$\frac{\text{Effective } Q \text{ of amplification curve}}{\text{Actual } Q \text{ of tuned circuit}}$$

$$= \frac{1}{1 + \frac{\mu L Q}{R_p} + \frac{\mu L Q}{R_{gl}}}$$







## CHAPTER 6

### POWER SUPPLIES

#### MAKING THE ELECTRONS FLOW

Probably you were too young back in the early 20's to remember the old family radio set with its automobile storage battery under the table to supply power—and Dad had to lug the battery downtown to the garage every week for a recharge—or he may have had a Tungar charger in the basement to recharge it at home—and Mom hollered her head off about holes eaten in the living room rug by the battery acid. Remember the big heavy square “B” batteries that had to be replaced pretty often? And later, the “C’s” that lasted almost forever?

Nowadays, except for a few battery-operated sets far out in the country away from power lines, and except for the picnic portable sets, all home radios simply plug into an electric light socket. The 110-volt, 60-cycle a.c. is rectified and changed around to fit the needs of the various detector and amplifier tubes in the set.

#### HALF-WAVE RECTIFIERS

You remember that the simple diode will pass only positive cycles of current. When you use the diode as a rectifier of a.c., in the circuit shown in figure 112*A*, only the positive half of each complete sine

wave is passed, and your output curve of current looks like figure 112B. The negative loops of a.c. are lost, since no current flows through the diode on the negative alternations. The output current is PULSATING D.C.

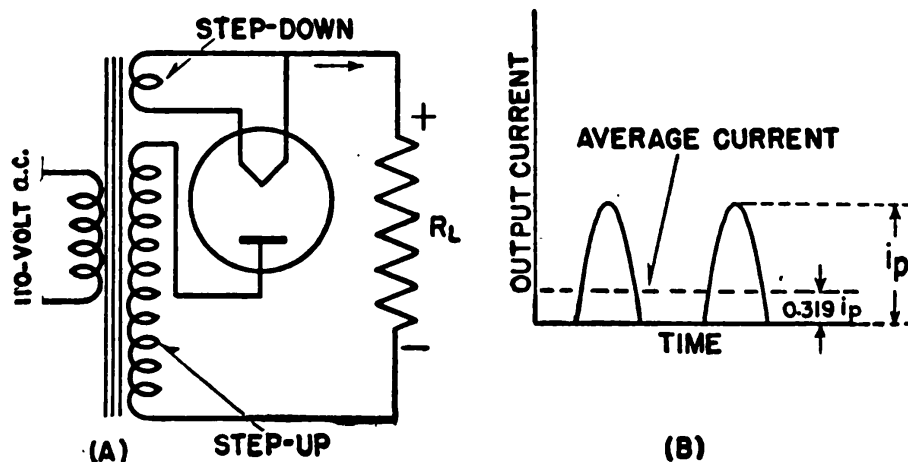


Figure 112.—Half-wave rectifier.

If you compute the height of a rectangle having the same length as the wave length of a sine wave and the same area as that enclosed by half a sine wave,

you'll find that the height is  $\frac{1}{\pi}$  or 0.319 of the peak

value of the sine wave. Thus, you can find the average current throughout the cycle by multiplying the peak value of the sine wave by 0.319. This value is indicated by the dashed line on figure 112B. Since the peak anode current for any tube is limited by the emitting power of the cathode, this constant, 0.319, determines the maximum load current that the tube can supply.

The maximum voltage across the tube occurs when the tube is idle on the non-conducting or negative loop of the alternation, when the plate is negative to the cathode. This value of  $E_{max}$  is equal to the full peak voltage of the transformer secondary, and is called the INVERSE PEAK VOLTAGE.

## FULL-WAVE RECTIFIER

If you could somehow fill in the blank spaces between the half-sine loops of figure 112*B*, your supply of rectified d.c. would be much smoother and regular. And you can do this by putting a second plate in a diode envelope, and leading off a center tap from the transformer secondary to the cathode, as in figure 113*A*. A vacuum tube of this type is called a FULL-WAVE RECTIFIER or DOUBLE DIODE.

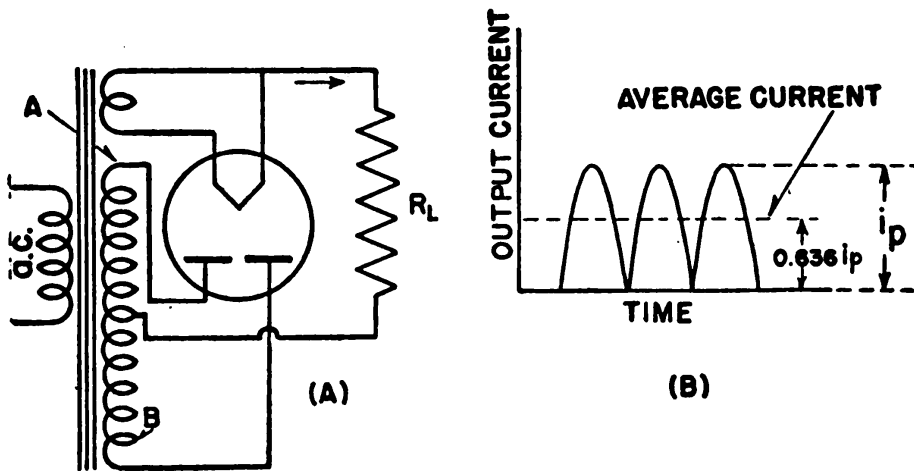


Figure 113.—Full-wave rectifier circuit.

Here's how the full-wave rectifier works—

When the upper half (*A*) of the step-up transformer secondary is receiving a positive alternation, current flows through the left-hand plate of the double diode to the load  $R_L$ . On the next alternation of a.c., the lower half (*B*) of the transformer becomes +, and current flows through the right-hand plate to  $R_L$ . Note that the direction of current through  $R_L$  is always in the same direction. Both halves of each alternation of the a.c. supply are used.

The constant,  $\frac{2}{\pi}$  or 0.636, is used to determine the AVERAGE CURRENT from peak current. The full-wave rectifier gives a better wave form than the half-wave

rectifier, and also provides symmetrical transformer action.

Because the two rectifiers work alternately, each half of the transformer secondary also works alternately, and each half must be wound to carry the full-load voltage. If you assume a negligible voltage drop in the rectifier which is carrying a positive current at any instant, you can say that the other rectifier at that instant carries an inverse peak voltage equal to the maximum voltage across both halves of the transformer.

In addition, the inverse peak voltage rating of a full-wave rectifier tube would have to be twice that of a diode used to handle the same peak output voltage. However, each plate of the full-wave rectifier carries only half the load current, since energy is delivered to the load at twice the average rate of a half-wave rectifier.

Since the insulation between the cathode and the plate of a full-wave rectifier must withstand the full voltage across the secondary, you can see that the insulation must withstand TWICE the voltage that would be impressed on a half-wave rectifier.

### **GAS-FILLED RECTIFIERS**

The GAS-FILLED TUBE usually contains a drop or two of mercury which vaporizes when the cathode is heated, and ionizes when you apply the plate voltage. The positive ions cancel out the space-charge effect and lower the plate-to-cathode voltage drop to an almost constant value of about 15 volts, regardless of what the plate current is.

Here are the advantages of the gas-filled tube: Voltage drop is practically constant for all operating currents, and power losses across the tube are less than for ordinary thermo-ionic or high-vacuum conduction.

ONE PRECAUTION—Never apply the plate voltage to a mercury-vapor tube until the cathode has been heated up to operating temperature. Otherwise, the electron emission from the cathode will be low, voltage drop across the tube will be too high, and the cathode will be severely bombarded by positive ions. Serious disintegration of the cathode surface will result.

ANOTHER PRECAUTION—If you exceed the rated inverse-peak voltage of a mercury-vapor tube, you are likely to cause ARC-BACK, or breakdown of the mercury vapor, which causes the direction of conduction across the tube to be reversed.

AND ANOTHER—Be sure your cathode is at correct operating temperature. If the voltage at the heater or filament is too low, arc-back will occur. Check the voltage AT the tube socket to avoid errors caused by voltage drop in the leads to the socket. When you first put a new tube into operation, or restore a tube to service after a long period of idleness, you should heat the cathode for about 10 minutes before turning on the plate current, to prevent arc-back.

If you operate mercury vapor rectifiers in parallel, you'll have to take some precautions to make each

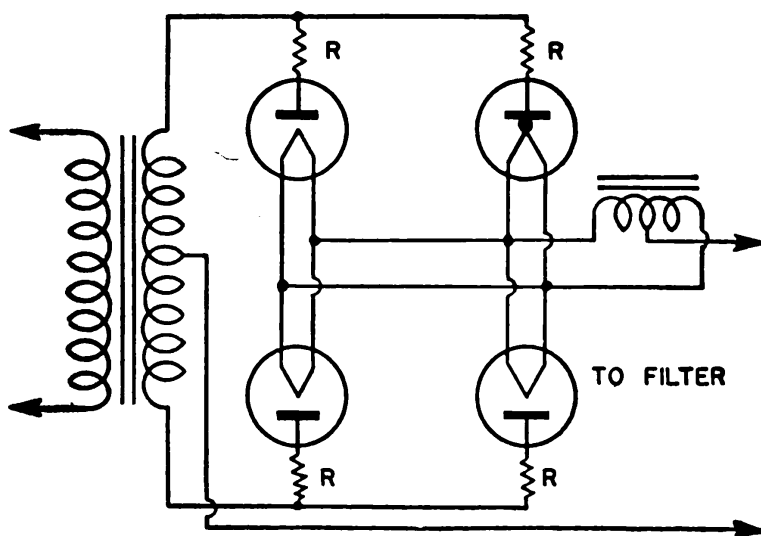


Figure 114.—Mercury-vapor rectifiers in parallel.

tube start. The slight differences in construction and characteristics of two tubes of the same type may make one tube ionize at a lower voltage than the other tube. Since the ignition voltage of a tube is much higher than its operating voltage, the tube that ionizes first carries the whole load, and the voltage drop is then too small to ignite the second tube. How to prevent this?

Put in resistors  $R$ , as in figure 114, in series with each plate. Then a voltage high enough to ignite each tube will be supplied to each cathode.

### COPPER-OXIDE RECTIFIERS

This type of rectifier makes use of the fact that a sandwich made up of alternate layers of pure copper and copper-oxide will pass current in one direction about 3 times as readily as in the opposite direction. The copper and copper-oxide are made up into washers or circular plates about  $1\frac{1}{2}$  inches in diameter and bolted together at a carefully calibrated pressure at the factory. If you loosen or tighten the pile of washers, you change the rectifier characteristics of the assembly.

You'll use copper-oxide rectifiers for changing a.c. to d.c. for measuring purposes, and you can also replace the dry cell that supplies current to a microphone. You can excite the field coils of a dynamic speaker with a copper-oxide rectifier, and in broadcast station operation. You'll find these rectifiers used in station and voltage amplifiers and condenser microphones. This type of rectifier has been replaced by the gas-filled tube rectifier for battery charging and B-battery eliminators.

Copper-oxide rectifiers have an efficiency of about 60-70%, and are used mostly for rectifying low voltages at low power. The rectifiers must be kept

cool, about  $140^{\circ}$  F., for satisfactory operation and long life. Some units have operated satisfactorily for over six years.

## VOLTAGE DOUBLERS

Here's where you'll think you get something for nothing!

The VOLTAGE DOUBLER is a type of tube that gives full-wave rectification AND delivers twice as much d-c voltage as its a-c input. A circuit including a

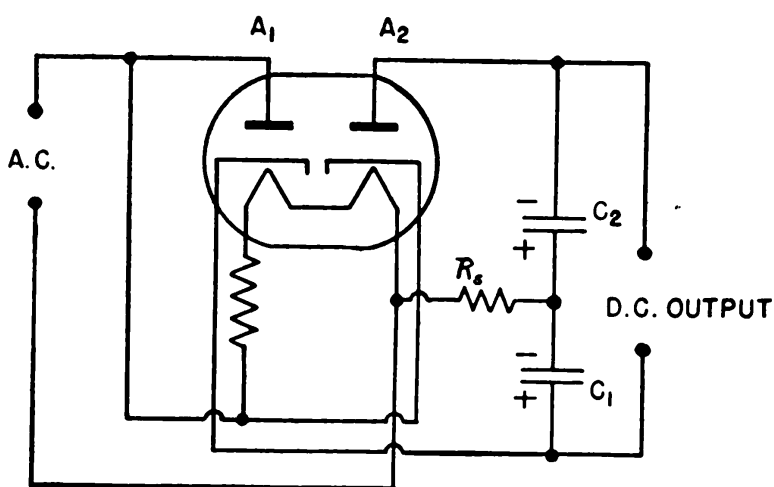


Figure 115.—Voltage-doubler tube circuit.

voltage-double tube is shown in figure 115. You'll see that the tube is actually two complete diodes sealed in one glass or metal envelope.

How does it work?

On the positive alternation of the 110-v, a.c., plate  $A$  is positive and current flows through  $A_1$  into condenser  $C_1$ . On the negative alternation, plate  $A_2$  becomes charged, and current flows into  $C_2$ . Since the two condensers are in series with respect to the d-c output, the sum of their voltages is available.

When you connect a load to the output terminals, you draw the load current from the two condensers, reducing their voltage between charging periods.



Both condensers are charged to peak input voltage, so you get out a value of peak line voltage at the d-c output.

If you use very large condensers, at least  $16\ \mu\text{f.}$  and up to  $40\ \mu\text{f.}$  in many voltage-doubler circuits, you cut down the decrease in voltage as the condensers discharge, and also get better voltage regulation.

While large capacity condensers improve regulation, they allow the passage of very high charging currents which may injure the voltage-doubler tube. You can limit this maximum tube current by putting a series resistance  $R_s$  in the circuit. Resistance  $R_s$  is in series with each condenser as it is being charged, and limits the charging current on each half of the cycle.

The voltage doubler provides a transformerless plate supply of moderately high-voltage d.c. that can be used with light loads.

## FILTERS

If you look back at figures 112*B* and 113*B*, you'll see that the output from either a half-wave or a full-wave rectifier is pulsating d.c., which won't work well in most vacuum-tube applications. For example, B-supplies must be as free as possible from "ripples." You smooth out these ripples by running the pulsating d.c. through the inductance and capacitance of a FILTER CIRCUIT.

The filter makes use of the energy-storage properties of an inductance and a capacitance. You remember that this combination of inductance and condenser stores up electrical energy when the current and voltage are rising, and return this energy to the circuit when the current and voltage fall on the alternation. In this way, the "valleys" and "hills" in the current or voltage curve are smoothed out. The smaller the valleys or RIPPLES in the pulsating d.c., the easier it is to filter. And, the higher the

RIPPLE FREQUENCY—the more ripples there are per cycle of input frequency—the easier it is to filter.

You also recall that the choking action of a coil in series with a mixed a.c. - d.c. will reduce the a.c. portion while allowing the d.c. portion to pass. If you connect a condenser across the line, the a.c. will by-pass, but the d.c. will not be affected.

You'll run into two types of filters—CHOKE-INPUT and CONDENSER-INPUT. Here's how they work—the choke-input type first, since it's the more common.

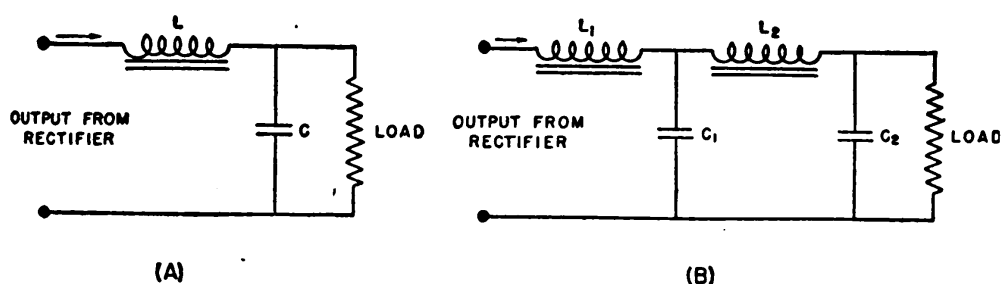


Figure 116.—Choke-input filters.

Look at figure 116 for diagrams of the single-section (A) and double-section (B) CHOKE-INPUT FILTERS.

The pulsating d.c. flowing through inductance  $L$  in figure 116A encounters a high reactance at ripple frequency, but very little resistance to the d.c. component. Thus the ripples are greatly reduced. Condenser  $C$  in parallel with the load absorbs most of the remaining d.c. fluctuations, since the condenser reactance at ripple frequency is less than the load resistance. If you want further ripple reduction, add a second section to the choke-input filter, as in figure 116B.

The percentage of ripple for a SINGLE-SECTION choke-type filter is

$$\% \text{ Ripple} = \frac{100}{LC}$$

where  $L$  is in henries, and  $C$  is in  $\mu$  fd. For this type of filter the percentage of ripple should be less than

5 percent, the economical limit for ripple with a single section.

Greater reduction of ripple—to 0.25% or even less for radio receivers—is obtained by using a TWO-SECTION filter. The percentage of ripple for this type of filter is

$$\% \text{ Ripple} = \frac{650}{L_1 L_2 (C_1 + C_2)}$$

In figure 117, you see the diagram for a single-section condenser-input filter. Here's how it works—

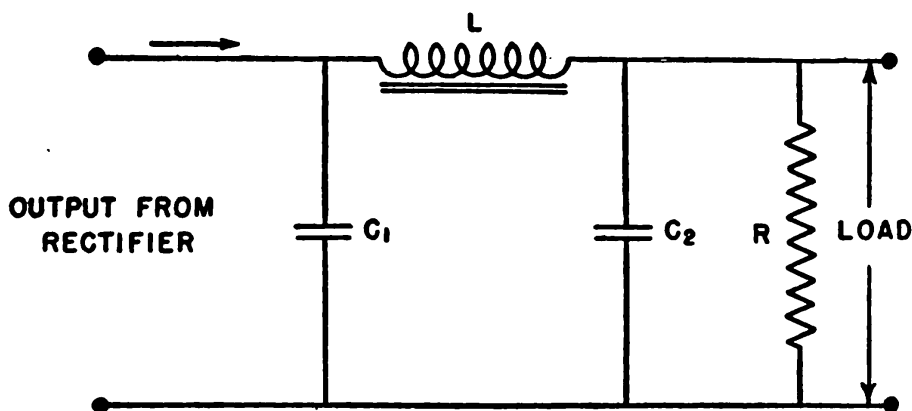


Figure 117.—Condenser-input filter.

Condenser  $C_1$  is charged to peak voltage directly from the rectifier, and this charge is withdrawn gradually by the load current. The coil and condenser,  $L_1$  and  $C_2$ , smooth out current and voltage fluctuations in the same way as did the choke-input filter above. The rectifier supplies no more current until the voltage across  $C_1$  is reduced below the voltage of the rectifier.

Here's how the two types of filters DIFFER—

Current flows continuously in the choke-input filter, but flows only a short part of a cycle in the condenser-input type. And for equal d-c load currents, the condenser-input filter will draw a higher peak plate current from the rectifier than will the

choke-input type. So, rectifiers that supply large amounts of current usually use CHOKE-INPUT filters.

But—the d-c output voltage of a choke-input filter is usually equal to the PEAK rectified voltage at light loads. The size of the condenser determines the voltage drop as load comes on, hence a larger input condenser will permit you to supply a larger output voltage for equal a-c supply. And so, power supplies for radio receivers and amplifiers are usually filtered with condenser-input filters.

### SWINGING CHOKES

In order to save weight and cost, you can use a SWINGING CHOKE with high values of inductance that will provide satisfactory operation over a wide band of load currents. A swinging choke is designed to have large inductance at low currents, and much smaller inductance at higher currents.

For example—you may have a bleeder resistance of 20,000  $\Omega$  and a full-load resistance of 2,500  $\Omega$ , including the bleeder. A choke that swings from 20 h. to 5 h. over the full output-current range will do the job.

And next you run into RESONANCE in the series circuit across the rectifier output. And you have to get the resonance out of there. This resonance is caused by the series combination of the first choke ( $L_1$ ) and the first filter condenser ( $C_1$ ) in the rectifier output circuit, and will cause the ripple voltage to build up too high.

You can't let the ripple voltage build up for a couple of reasons—the filter wasn't put in the circuit to build up ripple voltage, but to hold it down; and a high build-up of ripple voltage will cause excessive rectifier peak currents and inverse peak voltages. Here's a sample—

If you use full-wave rectification on a 60-cycle supply, the ripple frequency will be 120. Resonance will occur when

$$L \times C = 1.77$$

where  $L$  is the choke inductance in henries, and  $C$  is the condenser capacity in  $\mu$  fd. The figure 1.77 is a constant. For 50-cycle power, the constant is 2.53, and for 25-cycle power, it is 13.5.

You should choose values of  $L$  and  $C$  to double these constants if you want to prevent resonance, or choose  $L$  and  $C$  for 60-cycle power, for example, to make the constant at least  $2 \times 1.77$ , or about 3.7.

### POWER TRANSFORMERS

Since you already know how the transformer works to change the voltage of a.c., you need only a quick brush-up to focus the main points on transformers in your mind. Here it is—

As the a.c. through the transformer primary rises and falls from maximum + to maximum — through zero, the magnetic field around the primary winding induces an emf in the secondary winding of the transformer. The ratio of primary voltage to secondary voltage is proportional to the ratio of number of turns on the primary to number of turns on the secondary. For example—

You feed the 120-volt a.c. into the primary of a transformer that had 40 turns on the primary and 200 turns on the secondary. What's the secondary voltage?

$$\frac{120}{40} = \frac{x}{200} \text{ or } x = 600 \text{ volts, secondary.}$$

Now you can go ahead to applications of transformers for radio rectifier service. In figure 118, you see a VOLTAGE-REGULATING TRANSFORMER CIRCUIT. The two small transformers  $T_2$  and  $T_3$  supply the voltage regulation properties of the transformer  $T_1$ ,

which feeds the plates of the full-wave rectifier tube. Without the voltage regulation supplied by  $T_2$  and  $T_3$ , an increase in CURRENT LOAD on the secondary would cause a VOLTAGE DROP across the secondary.

Here's how the circuit shown in figure 118 prevents this voltage drop and maintains the voltage across the secondary of  $T_1$  regardless of the load put on the transformer—

As you increase the current drawn by the load, you increase the flux in the cores of  $T_2$  and  $T_3$  toward the saturation point. This reduces the reactance in the primaries of these two transformers. And you can apply a higher voltage to the primary of  $T_1$ ,

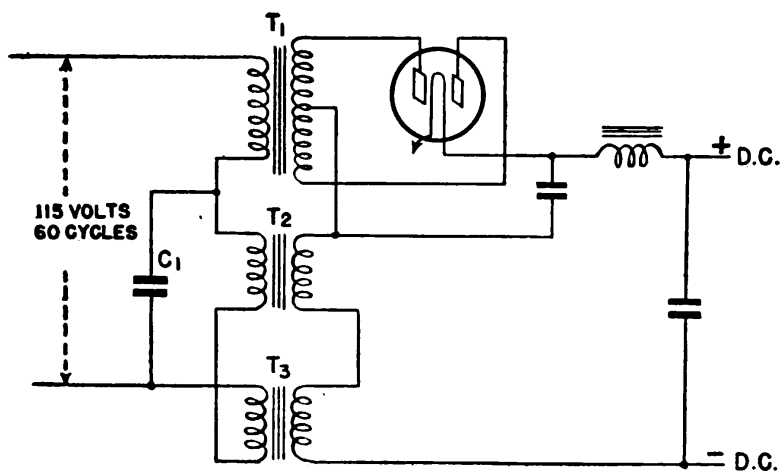


Figure 118.—Voltage-regulating transformer circuit.

thereby maintaining the output voltage of  $T_1$  at a steady level. The secondaries of  $T_2$  and  $T_3$  must oppose and be balanced against each other, or you will develop a severe ripple in the d-c output of the rectifier.

You vary the transformer regulation by selecting various capacities for condenser  $C_1$ , which shifts the phase relations of  $T_2$  and  $T_3$ .

In many high-grade transformers, you'll find an electrostatic shielding between the primary and the secondaries. It's put there to prevent the transfer of high-frequency disturbances in the power lines to

the tubes that are connected to the transformer secondary. Shielding also protects the power lines from disturbances caused by the tube circuits. The shielding is grounded through the transformer case to the ground, and by-passes all electrostatic emf's passing between shield and transformer on to ground.

The electrostatic shielding somewhat reduces tunable hum and key-click surge, and keeps radio-frequency currents from getting in the power circuits.

You'll find fuses in the primary circuit of most power transformers to protect them against overloads. The fuses usually blow at 50 percent over normal rated transformer current.

### THREE-PHASE POWER SUPPLY

As a power supply for transmitters requiring more than 1 kw. of d-c power, you can use a POLYPHASE RECTIFIER circuit, such as is shown in figure 119. This

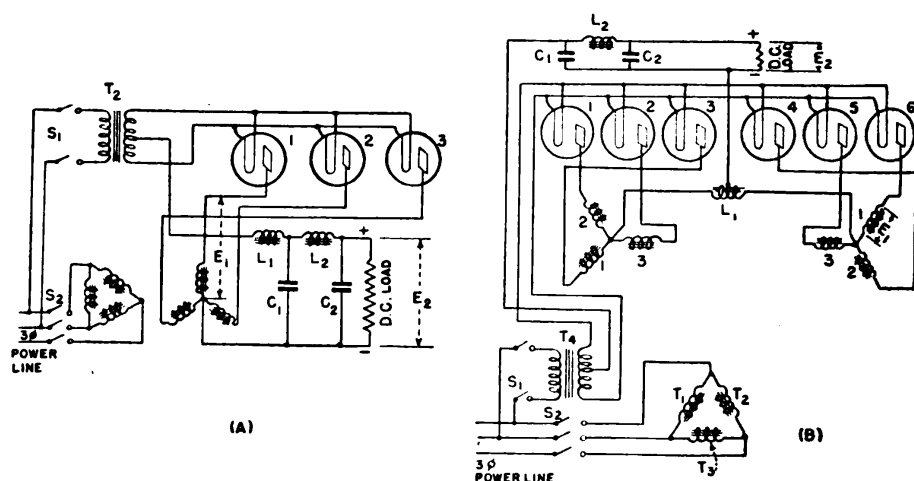


Figure 119.—Three-phase rectifier.

circuit rectifies 3-phase a.c. to a reasonably steady output voltage having a wave form close to that of steady d.c. Here's how you do it—

Figure 119A is a THREE-PHASE HALF-WAVE RECTIFIER, to which you feed 3-phase a.c. The a.c. is

carried by the plate that is MOST positive at the instant. Thus, each tube carries the current one-third of the time, and the output pulsations occur at three times the supply frequency. But you have to use a 3-phase transformer; or use three single-phase transformers, connected in delta-wye.

In figure 119B, you have a THREE PHASE FULL-WAVE RECTIFIER. This circuit is arranged so that in each phase the current is being carried by two tubes. Thus, current output is twice that of the 3-phase HALF-wave rectifier, and there are twice as many ripples per cycle of supply. Percentage of ripple is much reduced, and the current supply is much smoother.

## VOLTAGE DIVIDERS

After you've run the power from the supply lines through rectifiers and filters, you are ready to divide it up and feed it to the various tubes of your receiver or transmitter. If you have more than one tube-circuit, you'll probably need power at several different voltages. VOLTAGE DIVIDERS are in style again!

You'll recall from Chapter 1 of this manual that VOLTAGE DIVIDERS are simply resistances connected across the voltage supply, with taps on them at various points to lead off the desired voltages. In figure 120, you have a typical voltage divider circuit for a vacuum-tube supply. Take a few minutes to trace out this diagram, and you'll have a clear picture of the fundamentals of voltage dividers as power supplies for vacuum tubes.

There's a difficulty, however, in using a voltage-divider circuit as a power supply. Since the voltage at a tap depends on the current being drawn from that tap, voltage dividers give poor regulation. Or, you can apply the voltage from the divider to an electronic voltage regulator, such as a gas-filled tube, before feeding it to the radio circuit.



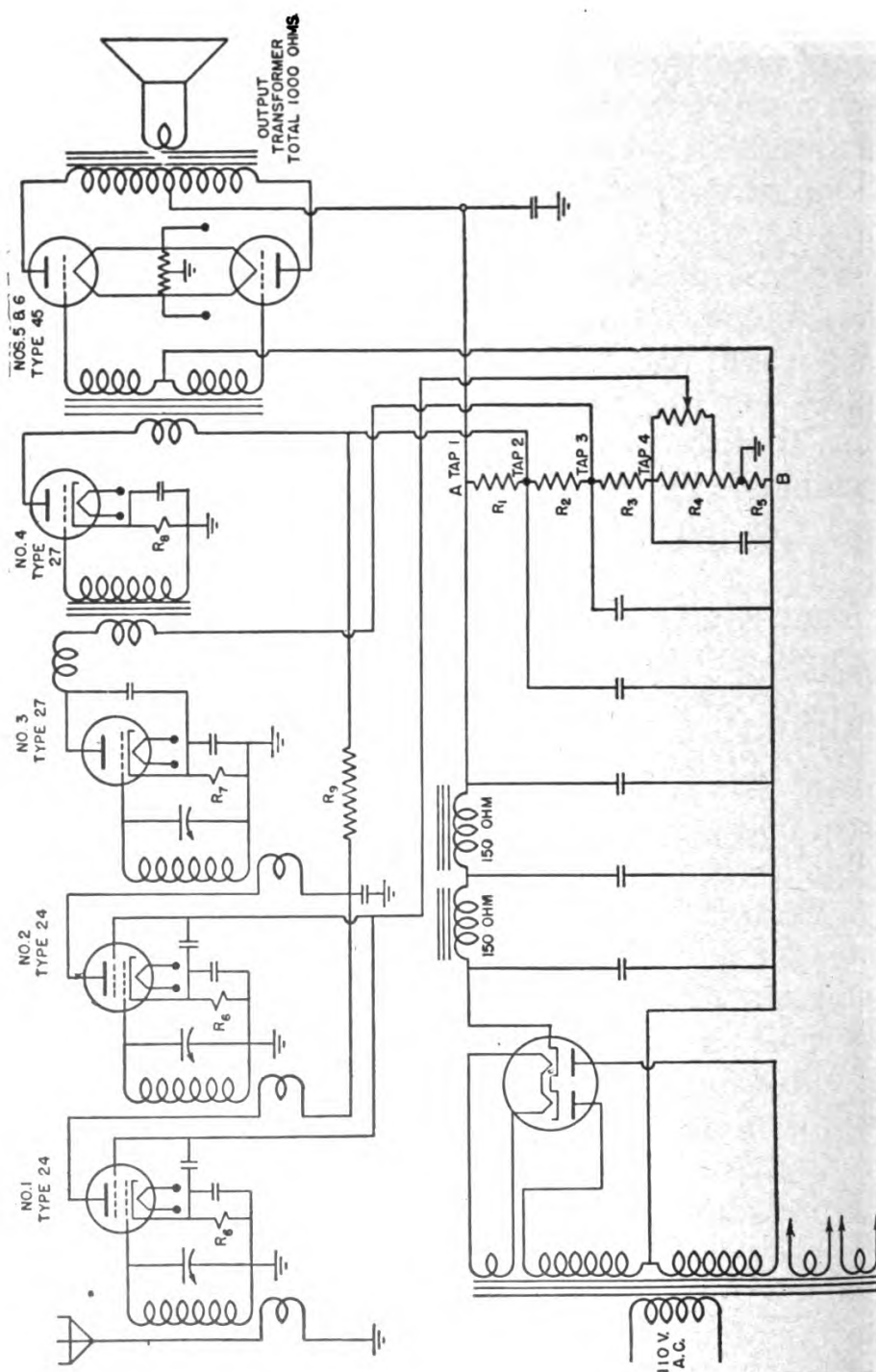


Figure 120.—Voltage-dividers for vacuum-tube circuit.

## STORAGE-BATTERY POWER

Once in a coon's age, you'll have only low-voltage d.c., say a 6-volt automobile storage battery, available for radio power. You can make use of this power by running it through either a VIBRATOR or a DYNAMOTOR.

The VIBRATOR uses a magnet coil which is alternately energized and de-energized to break up the low-voltage d.c. into low-voltage a.c. This a.c. is stepped-up in a transformer, then converted back to high-voltage d.c. for plate power by running it through a rectifier tube. The vibrator is a cheap device for getting plate power from a storage battery, but is short-lived and requires a complicated filter and shielding system to prevent interference in the receiver.

The DYNAMOTOR is a combination motor-generator set, having two separate armature windings and a common field circuit. The motor armature winding is fed from the 6-volt battery, and drives the second armature as a generator to produce the required higher-voltage d.c. The dynamotor is longer-lived and freer from trouble, but much more expensive.

## GLOW TUBES

For a few special jobs, you'll need a supply of d-c voltage that is ENTIRELY free from any voltage fluctuations. Even the relatively smooth output of the rectifier-filter isn't smooth enough. Then you put a glow-discharge voltage-regulator tube into the circuit, as in figure 121. This type of tube holds a constant d-c output voltage across the load, no matter what the load-current and load-voltage variations are. Changes in the supply voltage will affect the current through the tube, but have no effect on the load voltage and current.

To keep the current through these glow-discharge tubes from going above their maximum d-c operating

current of 30 ma. under no-load, you always use a series resistance in the line.

In figure 122, you see a voltage-stabilizing circuit

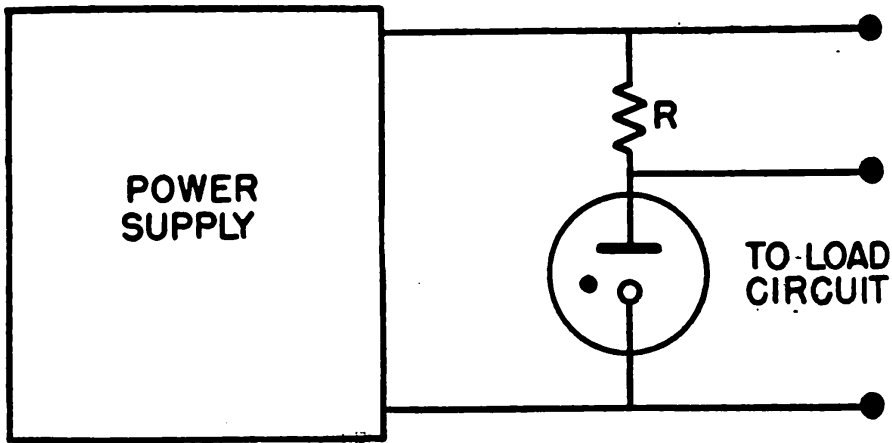


Figure 121.—Glow-discharge voltage regulator.

which gives stabilization within 1 volt at 300 volts for line or load changes of 25 percent. The triode

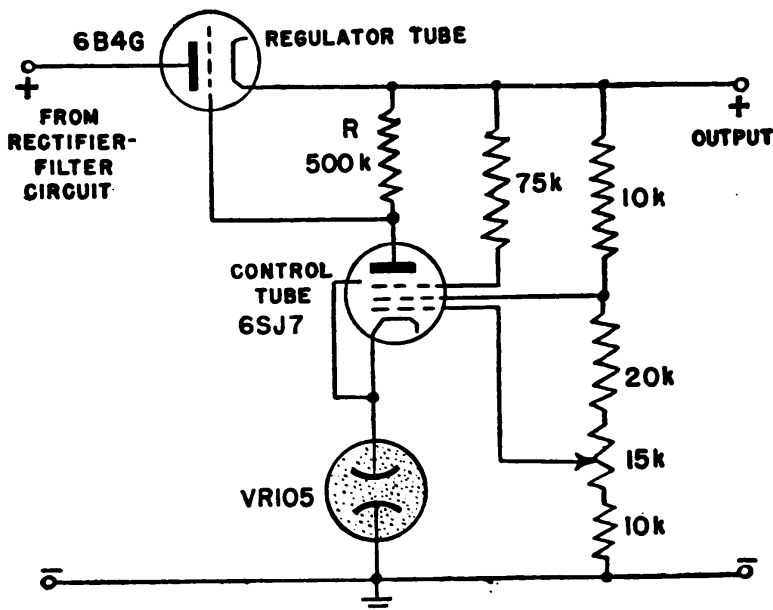


Figure 122.—Voltage-stabilizing circuit.

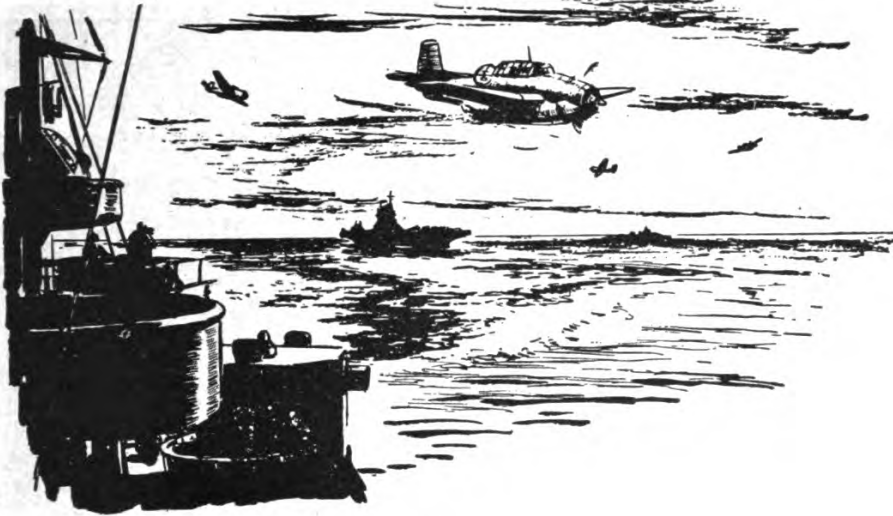
regulator tube 6B4G has its resistance changed by the grid-bias change developed across resistance  $R$  by the plate current of the control tube 6SJ7. This

changes the voltage and the plate current across the 6SJ7.

Suppose the voltage at the top of resistance  $R$  rises. The bias voltage and the internal resistance of the 6B4G will rise, and the voltage at the top of  $R$  will return to normal.

The rest of the circuit in figure 122 is used as a voltage-divider circuit to put the correct voltages on the grids of the 6SJ7 to help stabilize the output voltage. The constant voltage across the VR105 glow-discharge tube holds the cathode of the 6SJ7 at a constant voltage.





## CHAPTER 7

### TRANSMITTERS

#### YOU'RE ON THE AIR

Ever hear about the studio pianist who was playing the piano accompaniment for a young lady who just plain couldn't sing? After struggling along for several measures trying to keep in key with her, the pianist finally gives her a look and says, "Look, miss, I've tried playing on the white keys, I've tried playing on the black keys, but you always manage to sing in the cracks."

And in order to keep your transmitter out of the cracks, you have to design it to send out stable radio signals that are free from SPURIOUS or unwanted radiations. The r.f. carrier must be free from amplitude variations caused by fluctuations in the power supplies, and must not be affected by load variations and changes in circuit constants.

The simplest form of transmitter consists of an OSCILLATOR and an ANTENNA. But you can't get a very large supply of STABLE power out of an oscillator. So you use the oscillator only to generate a signal

at a certain frequency. Then you run this power through amplifiers to build it up to a usable size.

The stage that builds up the power of the signal at ORIGINAL SIGNAL FREQUENCY is the STRAIGHT AMPLIFIER stage. The stage that takes the harmonic output from the original signal generated by the oscillator and amplifies it is called the FREQUENCY MULTIPLIER or DOUBLER. And sometimes you use a BUFFER, which is an amplifier stage set between the antenna and the oscillator to prevent load variations from upsetting the oscillator frequency. Sometimes you can make a buffer do double-duty as a BUFFER and a DOUBLER. And finally you have the POWER AMPLIFIER that delivers the completed signal to the antenna.

The ordinary garden-variety TRANSMITTER is usually made up of an OSCILLATOR, a BUFFER-DOUBLER amplifier, a final or POWER amplifier, and the antenna circuit. You use as many amplifier stages as are required by the power and frequency needs of the transmitter. You usually design a transmitter to work on several frequency bands. You can switch frequencies either by changing PLUG-IN assemblies of condensers and inductances or by switching to various selected BUILT-IN COILS and capacitors.

## OSCILLATOR CIRCUITS

You use an oscillator circuit to convert the d.c. from the power supply into a.c. at the desired frequency. The a-c voltage controls the frequency of the transmitter wave. This voltage must be constant in frequency, and must not be greatly distorted by voltage changes in the power source, by changes in temperature, nor by changes in loading as the circuits controlled by the oscillator are tuned.

And a vacuum tube in a well-tuned circuit gives you this kind of constant r-f voltage. The tube is able to amplify the voltage put across its grid circuit,

release power into the plate circuit, and feed-back part of this power into the grid circuit to make up grid losses.

## TANK CIRCUIT

Here's how you use a TANK CIRCUIT to set up

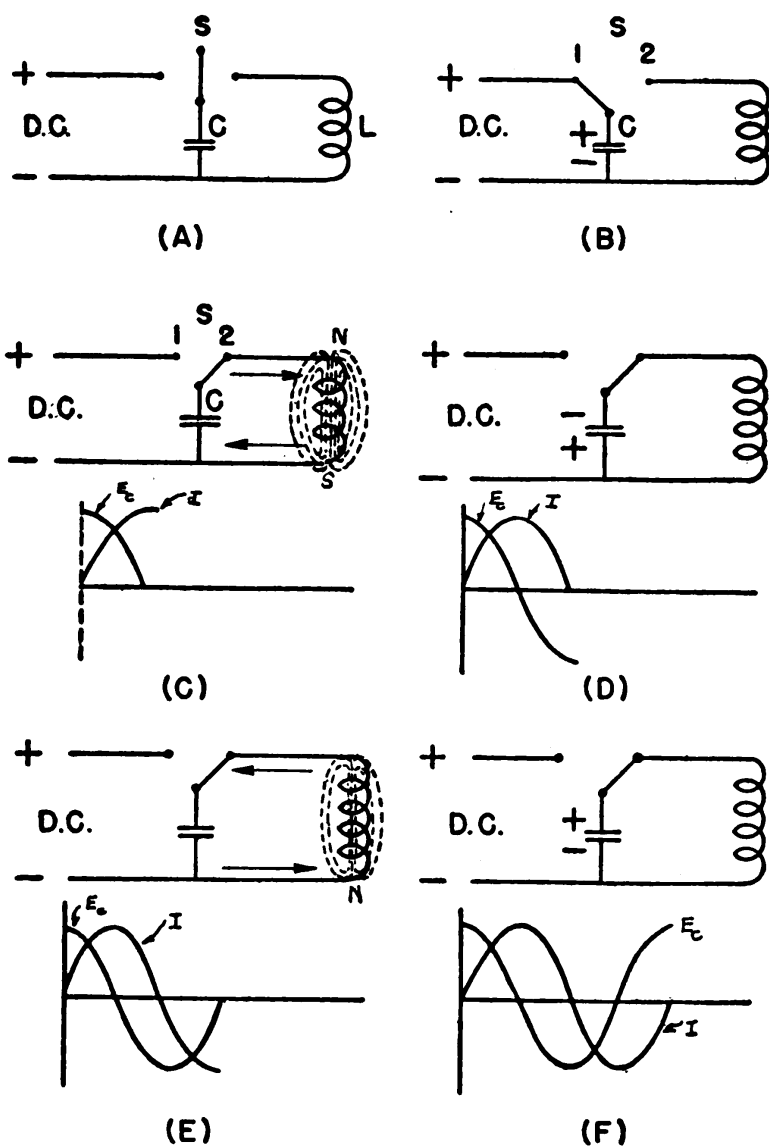


Figure 123.—Tank-circuit oscillator.

oscillating currents. A tank circuit consists of a coil and a condenser connected in a closed series circuit. Figure 123 gives you a series of circuit dia-



grams showing a tank circuit in operation. Here's what happens—

In figure 123*A*, the switch  $S$  is open, so that neither coil  $L$  nor condenser  $C$  are connected to the d-c supply. When you throw the switch to position 1, in figure 123*B*, the d-c supply is fed to the condenser, which comes up to full line voltage. As soon as you turn the switch to position 2, in figure 123*C*, the condenser discharges into the coil, condenser voltage dropping as the current increases.

Current flows through the coil to produce a magnetic field that grows until the current reaches its maximum value at the instant the condenser voltage becomes zero. This is shown in the voltage-current curves of figure 123*C*. You remember that current through a condenser lags voltage  $E_c$  by  $90^\circ$ . At this instant, practically all the electrostatic energy you stored in the condenser has been turned into energy in the electro-magnetic field around the coil.

The current can no longer increase, hence the coil flux begins to collapse, causing the current to continue to flow around the circuit. BUT at the same time, the condenser charges again, with OPPOSITE polarities, as in figure 123*D*. The charge continues until all the energy stored in the magnetic field of the coil has been returned to the condenser, and is stored as an ELECTROSTATIC charge. At this instant, the condenser carries a full voltage charge again, but the plate polarities are reversed from the polarities of figure 123*B*. The current flow is zero, and there is no field around the coil.

Now the condenser again begins to discharge through the coil, producing a strong electromagnetic field again. But polarities are again reversed, since current flow is now in the opposite direction. Discharge continues until condenser voltage is zero, current is maximum, and all the energy is again stored in the coil field, as in figure 123*E*. Next—

The field collapses again, charging the condenser in the opposite direction until condenser voltage is maximum, current drops to zero, and there is no flux around the coil, as in figure 123F.

And ONE CYCLE is completed.

Throughout all this transferring of current back and forth, no additional power has been fed to the circuit from the line. The only power you've lost is the tiny bit lost as heat through the connecting wires and the conductor in the coil and condenser. You could let your oscillator continue to operate forever but for this small gradual heat loss.

You can calculate the oscillator frequency from the capacity and inductance you have. And since at RESONANCE,

$$X_L = X_C$$

$$\text{And, } 2\pi fL = \frac{1}{2\pi fC}$$

$$\text{Therefore, } f = \frac{1}{2\pi \sqrt{LC}}$$

Where  $f$  = cycles/second.

$L$  = inductance, in henries

$C$  = capacity, in farads

Since the RESISTANCE is QUITE SMALL, the OSCILLATING TANK CURRENT can be VERY LARGE.

If you connect a tank circuit to a vacuum tube circuit, the vacuum tube circuit will oscillate continuously at its own resonant frequency as a VACUUM TUBE OSCILLATOR.

Likewise, by connecting a vacuum tube amplifier circuit so that it is SELF-EXCITED—supplies its own input voltage—in the correct phase and magnitude, the circuit will operate as an oscillator generator. This makes the tube operate similar to a class C amplifier.

To make a vacuum tube circuit self-oscillating, you must make the voltage fed back from the output and fed to the grid or input about  $180^\circ$  out of phase with the load impedance voltage. The basic difference between the various types of self-oscillating circuits is the method of obtaining the grid and plate voltages out-of-phase.

### HARTLEY OSCILLATOR

The Hartley oscillator, figure 124, is an example of one method of obtaining grid and plate voltages

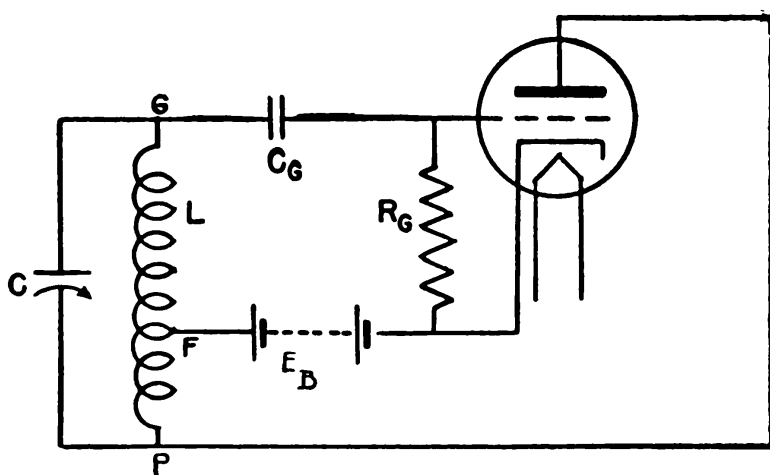


Figure 124.—Hartley oscillator.

out-of-phase. In this type, the phase relation between grid and plate is obtained by connecting the control grid and the plate of the tube to opposite ends of the coil  $L$ , and connecting the tube cathode to an adjustable tap  $F$  near the center of the coil. The voltage built up across coil  $L$  will be the product of the circulating current and the inductive reactance. The portion of this voltage between points  $F$  and  $G$  in figure 124 will be fed to the grid to act as driver voltage. The remainder of the voltage, between points  $F$  and  $P$ , is the alternating voltage in the plate circuit.

When you close the switch and throw the first surge of plate current into the coil  $L$  between  $F$  and  $P$ , you set up the initial oscillations. The rising plate current sets up a field around the coil, inducing an emf between  $F$  and  $G$ . This emf is positive on the grid with respect to the cathode. Plate current rises to a maximum value. Then, since no further rise in current can take place, there is no further cutting of flux in the coil between  $F$  and  $G$ . The result—

The positive emf applied to the grid is removed, plate current drops off and sets up a field with OPPOSITE polarity. Now you have a negative emf on the grid, to further reduce plate current to its minimum value. And that completes one cycle on the Hartley oscillator.

The plate circuit must draw enough power from the supply to replace these losses in the oscillator circuit—

The  $I^2R$  losses in the tank circuit

The  $I^2R$  loss in the grid leak, and

The power lost in the grid, as heat.

To make the self-oscillating circuit self-starting, you almost always use a GRID-LEAK form of grid voltage bias. If you used FIXED-BIAS, you'd probably bias the tube to a point beyond plate-current cut-off. In addition, to providing bias, the grid leak is self-regulating. Grid current flows only when the grid is positive, which is at the peak of the driving voltage. As this grid current flows through the grid leak in only one direction, it produces a grid-to-cathode voltage, with the grid negative. This bias voltage rises as the driving voltage rises, and you reach a point where the amplitude of oscillations is sustained at a given level.

The POWER OUTPUT and EFFICIENCY of the oscillator are determined by—

The grid bias, alternating grid voltage, d-c and a-c plate voltage, tube characteristics, and

the characteristics of the tuned tank circuit with its load.

In general, these factors are such as to make operation of the Hartley oscillator the same as that of a class C amplifier. However, the efficiency of the Hartley is a little lower, and it is generally lightly loaded to maintain frequency stability. LIGHT LOADING is attained by not making the oscillator furnish large amounts of power, and by keeping the load as constant as possible.

### COLPITTS OSCILLATOR

The Hartley oscillator uses MAGNETIC feed-back, whereas the COLPITTS OSCILLATOR in figure 125 uses CAPACITY FEEDBACK. You divide the voltage for the grid and the plate by using the voltage drops across two condensers  $C_1$  and  $C_2$ , in series. The instantaneous voltages at the ends of the circuit are opposite in polarity with respect to the cathode, hence are in the correct phase to sustain oscillation.

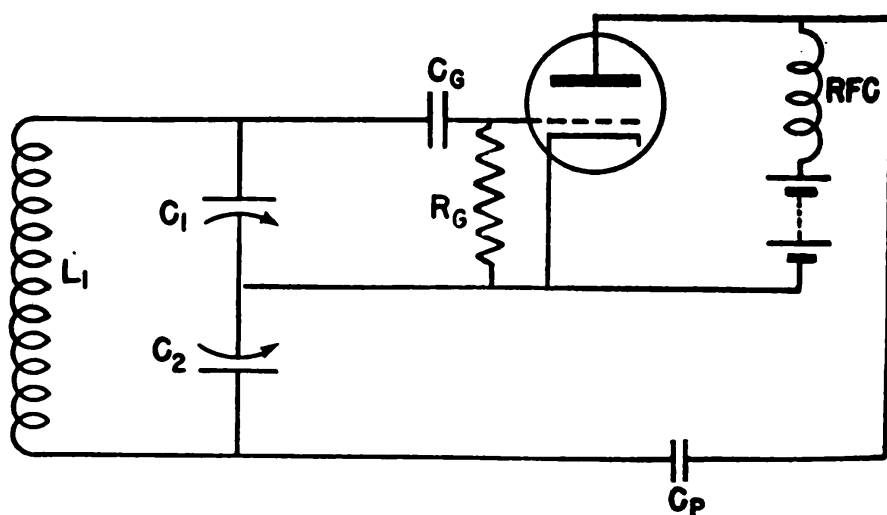


Figure 125.—Colpitts oscillator.

The grid voltage is always much less than the plate voltage, hence you choose a grid condenser  $C_1$  about three to four times as large as plate condenser

$C_2$ . You tune the Colpitts circuit by varying the number of turns on the tank coil  $L_1$ .

### TUNED-PLATE TUNED-GRID OSCILLATOR

In the TUNED-PLATE TUNED-GRID OSCILLATOR of figure 126, you use the GRID-TO-PLATE CAPACITY of the tube as a feed-back coupling between the grid and plate circuits. There shouldn't be any MAGNETIC coupling between the two tuned-circuit coils  $L_1$  and  $L_2$ . You adjust the feed-back by tuning the GRID

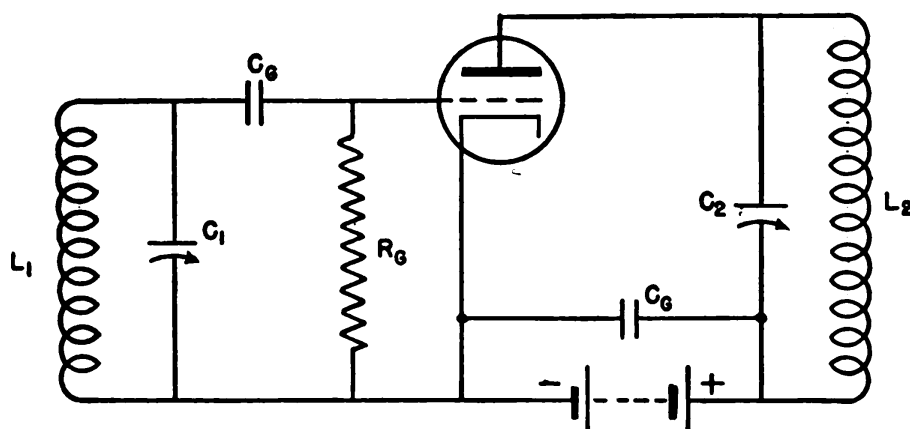


Figure 126.—Tuned-plate, tuned-grid oscillator.

TANK CIRCUIT and the PLATE TANK CIRCUIT. The frequency of oscillation is determined by which circuit you tune to the higher value of  $LC$ . The PLATE tank circuit should be tuned to a slightly higher frequency than the grid tank circuit so that the plate tank circuit will have inductive reactance and will give POSITIVE feed-back. You shouldn't have to DETUNE much, hence you can assume that the two tank circuits are tuned to about the same frequency.

### ELECTRON-COUPLED OSCILLATOR

You'll find the ELECTRON-COUPLED OSCILLATOR used in most types of Navy radio gear. This oscillator is especially useful in overcoming FREQUENCY

INSTABILITY caused by load variations. The diagrams for two types of electron-coupled oscillators are shown in figure 127.

In connection with this oscillator, you usually use a Hartley or some other oscillator tank circuit to determine the frequency of oscillation. This is the tank circuit  $L_1C_1$  in figure 127.

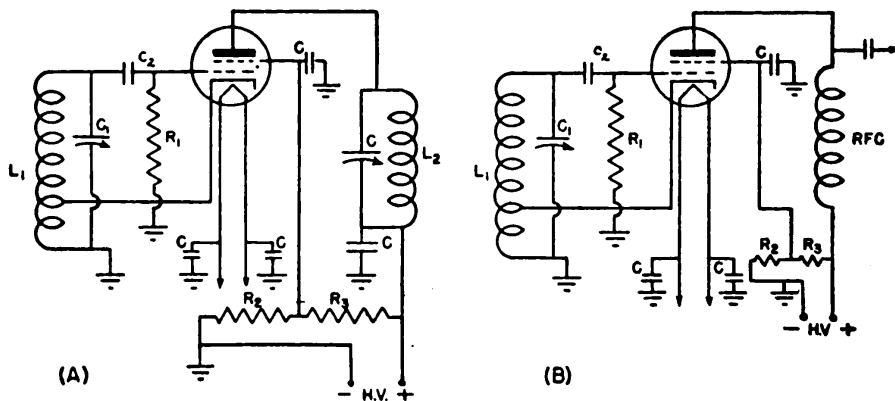


Figure 127.—Electron-coupled oscillator.

Here are the connections for the ELECTRON-COUPLED oscillator—

You connect the screen-grid tube so that its screen grid is used as a plate, in conjunction with the control grid and cathode, in a regular triode oscillator circuit. The screen operates at ground r-f potential to act as a shield between the plate and the cathode and control grid. Hence you must operate these shielded elements ABOVE ground potential. Output is taken from the plate circuit. So—the CAPACITY COUPLING between the plate and other ungrounded tube elements is quite small. And—you get the output power almost entirely by variations in the plate current. These variations are produced by the varying potentials on the grid and cathode. The plate VOLTAGE in a screen-grid tube has little effect on the plate current. Thus, the reaction on oscillator frequency for various loading conditions is negligible.

There are two types of output coupling shown in the diagram—TUNED, in figure 127*A*, and UNTUNED, in figure 127*B*. In the TUNED output circuit, a resonant circuit  $L_2C_2$  connected in the plate circuit can be tuned to the oscillation frequency or to one of the harmonics.

The UNTUNED output coupling of figure 127*B* lowers the output voltage and power a great deal, but provides BETTER ISOLATION between oscillator and amplifier.

If you use a pentode with an external supressor connection as the oscillator tube, ground the supressor grid to provide extra shielding and increase the isolation of the plate from the frequency-determining circuit. Also keep the grid-plate capacity LOW.

In addition to all the causes and cures of FREQUENCY INSTABILITY that affect the other types of oscillators, the ELECTRON-COUPLED OSCILLATOR is readily affected by changes in supply voltage IF the ratio of plate voltage is not picked correctly. The normal ratio is 3 to 1, BUT you should determine it EXPERIMENTALLY for each case.

Since the cathode is ABOVE ground potential, you should take care to keep down the effects of heater-to-cathode capacitance or leakage. These effects allow a small a-c voltage from the heater supply to develop between the cathode and ground, and can cause modulation at the supply frequency. You can reduce these effects by by-passing the heater, as in figure 127, or by operating the heater at the same r-f potential as the cathode.

For maximum stability of an electron-coupled oscillator, you should make the value of the grid-leak  $R_1$ , figure 127, at least 100,000 ohms. The grid condenser should be about  $100\mu\mu\text{fd.}$ , and the other fixed condensers from  $0.002\mu\text{fd.}$  to  $0.1\mu\text{fd.}$

In order to maintain frequency stability, constant strength, and freedom from undesired harmonics,



you should not operate electron-coupled oscillators to deliver large blocks of power. Let them deliver small amounts of power to power-amplifying circuits.

## CRYSTAL OSCILLATOR

You won't run into many CRYSTAL OSCILLATORS in the Navy radio gear, but they are used in almost all commercial and broadcast gear. So you'll want to know about them. First, what is a crystal?

### THE CRYSTAL

Paper-thin plates cut from quartz have the PIEZO-ELECTRIC qualities that make the best oscillator crystals. You'll recall that "PIEZO-ELECTRICITY" is an eight-cylinder word meaning the difference in voltage between the two faces of a crystal that is being bent or squeezed or subjected to other mechanical stress. About all you'll need to know about cutting these quartz crystals is that the angles and directions of cutting make a difference in the frequency-handling and voltage-carrying capacities of the crystals.

The ability of a crystal to vibrate at one known frequency is an advantage AND a disadvantage. The crystal will keep right on its rated frequency, but a different crystal is required for each frequency. Also, since crystals are very sensitive to temperature changes and to shock, you must handle them carefully. Too much voltage or too much feed-back will damage or even ruin them.

The crystal is mounted between two metal electrodes that conduct the current to the crystal faces. There are two types of mountings. One type has both metal plates in contact with the flats of the crystal. The second type has a narrow AIR-GAP between the top electrode and the crystal face. The width of this air-gap determines to some extent the frequency of the oscillations of the crystals. In both

types, the bottom electrode should be heavy in order to dissipate the heat generated in the crystal. Excessive heat generation causes the crystal to change frequency. And now—

### MAKING THEM OSCILLATE

The circuit diagram for a TRIODE CRYSTAL OSCILLATOR is shown in figure 128. Here you use the

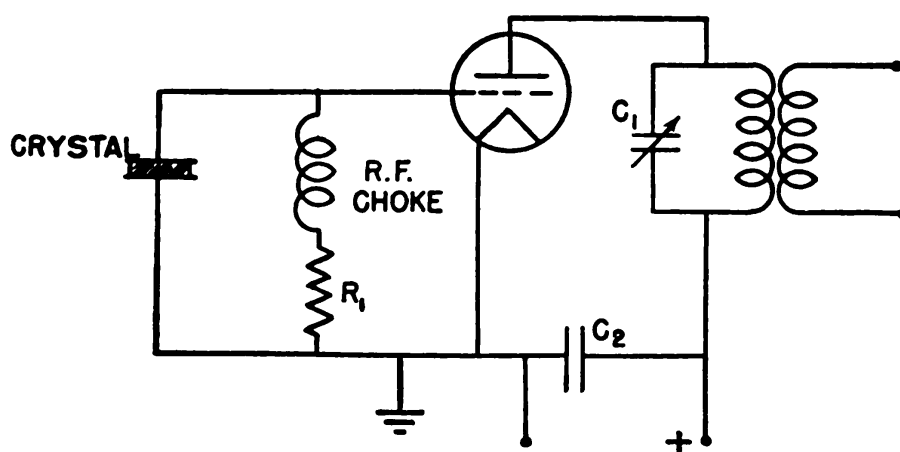


Figure 128.—Typical crystal-oscillator circuit.

crystal to control the frequency of the oscillator. The crystal replaces the tuned circuit that would normally be used to control frequency.

This circuit is a variation of the tuned-plate tuned-grid circuit, with the crystal replacing the grid-tuned circuit. The amplitude of oscillations is determined by the grid-to-plate capacity of the triode and the tuning of the plate resonant circuit.

The triode can be replaced by a pentode. The grid-plate coupling is provided either by the small left-over capacitance in the a-f power pentode or by a small external condenser in an r-f pentode. In either case, the coupling with pentodes is lower than with triodes.

You can also make the crystal furnish the coupling between the grid and plate circuits of an r-f pentode.

## KEYING A TRANSMITTER

You key a transmitter by having it adjusted so that it delivers FULL power to the antenna when the key is closed, and no power when the key is up or open. GOOD keying also requires that the output frequency of the emitted signal be unaffected by the keying operation. Also your keying should not produce any clicks, which would be a source of interference to other stations.

### PLATE CIRCUIT KEYING

It is possible to KEY any or all stages of a transformer by opening and closing the plate high voltage supply circuit. This method is not generally advisable and should never be used without a keying relay. Regardless of whether the key is placed in the positive lead or the negative return, the FULL supply voltage will be present across the key when it is open and is therefore a hazard to the operating personnel.

### POWER-SUPPLY KEYING

This is a method of keying in which you insert the key into the power supply itself, rather than into the connections between the power supply and transmitter. Figure 129 shows one type of power supply keying.

Grid-controlled rectifier tubes are used in the power supply of figure 128. You key the circuit by biasing the grids enough to cut off plate current flow when the key is open, and by removing the bias when the key is closed.

You can also key the primary of the plate power transformer. Both of these systems have the disadvantage of a LAG due to the TIME CONSTANT of the smoothing filter and your keying efficiency drops off at speeds above 25 words per minute. PRIMARY

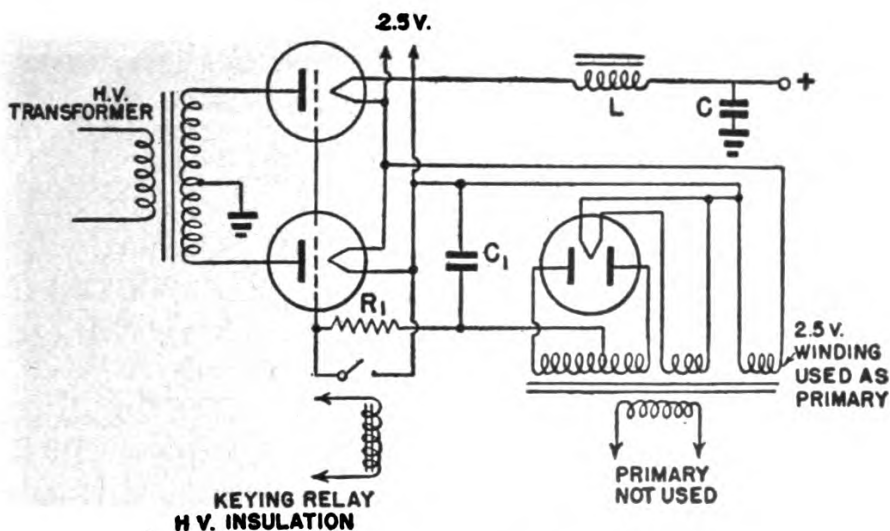


Figure 129.—Power supply keying.

KEYING is easily identified on the air by a BELL-TONE note that is characteristic of this type.

### CATHODE KEYING

If you open the d-c circuits of both the plate and the grid at the same instant, you get CATHODE KEYING, shown in figure 130. If you use this method on a direct-heated, filament type tube, it is called CENTER-TAP KEYING, since you put the key in the filament-transformer center-tap lead, as in figure 130B.

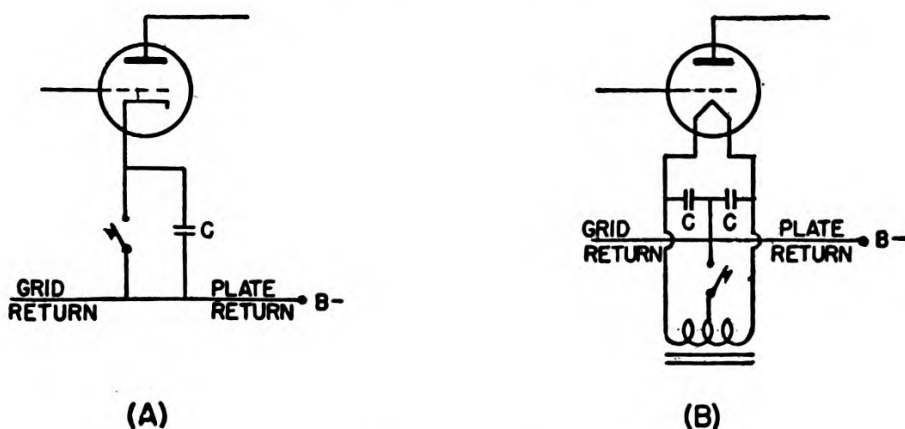


Figure 130.—Cathode keying.

With CATHODE KEYING you get less sparking at the key contacts for the same plate power, as compared to keying in the plate supply lead.

### BLOCKED-GRID KEYING

This is the system of keying that is usually used, and it is most satisfactory. For BLOCKED-GRID KEYING, you apply enough negative bias voltage to

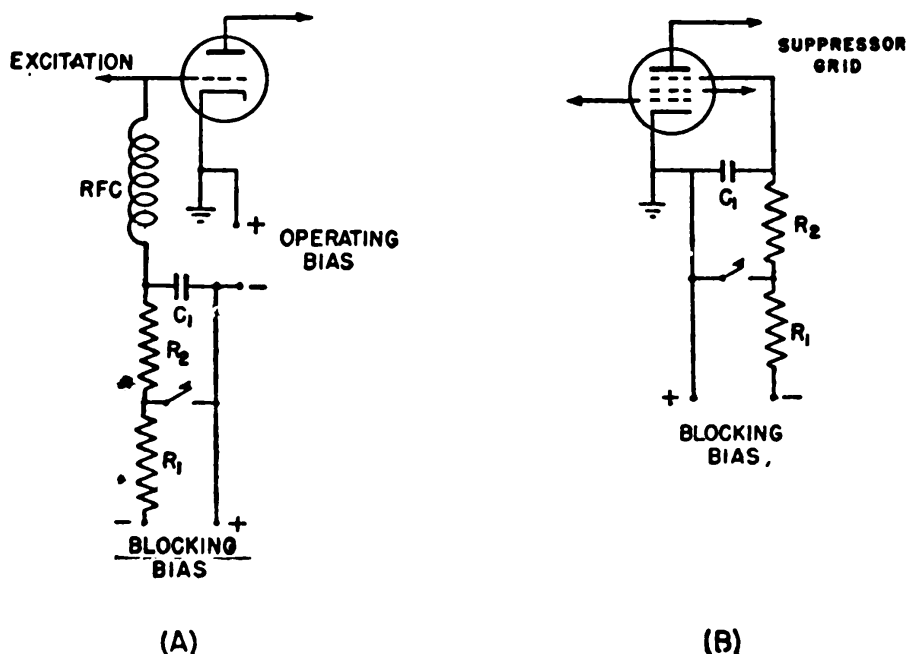


Figure 131.—Blocked-grid keying.

the control or suppressor grid to cut off plate current flow when the key is OPEN. You remove this BLOCKING BIAS when the key is CLOSED. The blocking bias voltage has to be large enough to overcome the r-f grid voltage, where you apply the bias to the control grid, hence must be MUCH HIGHER than the normal cut-off valve for the tube at the operating d-c plate voltage. You see a couple of BLOCKED-GRID KEYING circuits in figure 131. Here's how the circuit of figure 131A works—

The key is in series with resistor  $R_1$ , which limits the current drain on the source of blocking bias when

you close the key. The resistance-capacity filter  $R_2C_1$  controls the lag on make-and-break of the key. The lag increases as you increase the time-constant of this circuit. You'll remember that the time-constant is the time required for either charge or discharge of a condenser through a resistance, and that the time-constant is a product of the capacity and resistance, and is proportional to  $C$  and  $R$ .

When you close the key, grid current flows through  $R_2$ , and additional operating bias is developed. Thus, you'll need somewhat less bias from the regular bias supply. By using taps on a voltage divider, you can obtain your operating and blocking biases from one supply. If you have no fixed bias in your circuit, use the regular grid leak of the stage in place of  $R_2$ .

The advantage of BLOCKED-GRID KEYING is that you're breaking a relatively small d.c. as compared with the other keying systems. Thus, sparking is reduced. You can easily control keying lag by selecting proper values for  $C_1$  and  $R_2$ .

### OSCILLATOR KEYING

OSCILLATOR KEYING is seldom used in Navy equipment, except in small portable M.O.P.A. transmitters. There are several reasons why it is not suitable. First, the primary function of an oscillator, in well-designed transmitters, is to fix the frequency at which it is to operate and be a stable oscillator. Designers lean backward on this point and as a result, very little power is taken from the oscillator, constant-temperature compartments are employed, negative-temperature coefficient components are used to eliminate frequency drift and many other precautions are taken to insure that it will fulfill its primary functions.

It would therefore be foolhardy to KEY the oscillator, which is one of the greatest contributing factors toward instability. Also since oscillations must build-up, some time is required for the oscillator

to start working and produce full output. The signal is liable to be CHIRPY and will be unable to follow fast keying adequately.

Another reason for not keying the oscillator is that it is usually followed by a multi-stage amplifier which is operated in class C. These stages are usually self-biased by a grid-condenser and leak in order to take advantage of the self-adjusting bias feature. If the excitation to these stages is lost, the plate current through the individual stages will rise to enormous proportions and will result in damage to the tubes. For this reason the FINAL and intermediate power amplifiers are usually keyed while the oscillator and buffer operate continuously.

### KEY CLICKS

Now you come to the bug-a-boo of radio-telegraphy—key clicks, a source of interference to other stations. By suddenly making and breaking the keying circuit the signal rises abruptly and cuts-off sharply. This steep-sided wave contains many frequencies and harmonics which will be audible in the form of clicks over the whole frequency band. Sparking at the key contacts is another source of interference to stations located nearby.

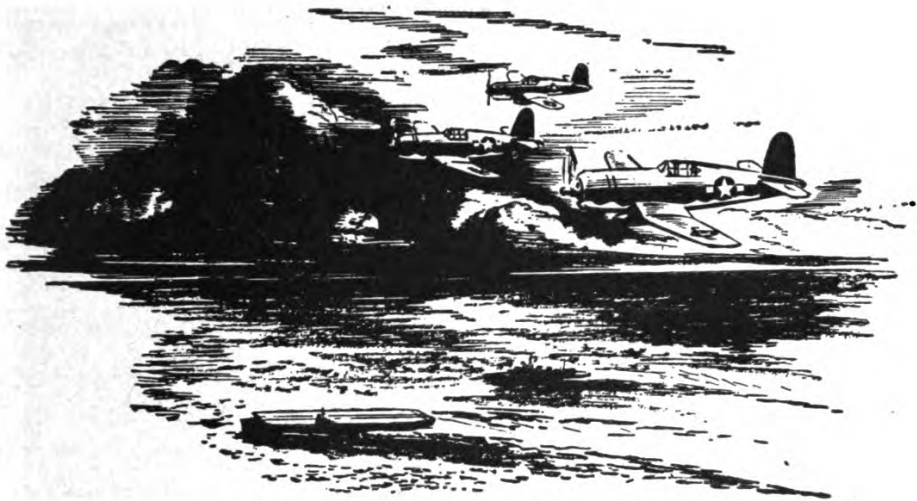
By eliminating the sparking you usually automatically decrease the increment and decrement of the output wave.

A common type of spark suppressor, or KEY-CLICK FILTER is a CHOKE in series with the key and a CONDENSER across the key contacts. Due to the inductance of the choke, the current is required to build up through it, thus taking care of the increment. However, if the key is opened, the voltage built up across the choke by self-induction, will cause an even greater spark to occur. By using the condenser, this sudden voltage surge will be absorbed and the decrement of the wave will be taken care of.

Another popular method of eliminating key-clicks is to use KEYING TUBES. Here the plate and filament of the tube are in series with the circuit to be keyed. Keying is accomplished by applying and removing a BLOCKING BIAS to the grid. Thus the tube acts as an electronic relay and a very small current is keyed. Care must be taken not to exceed the rated plate current value of the keying tube. If the circuit to be keyed draws a large current, several keying tubes may be operated in parallel.







## CHAPTER 8

### MODULATION

#### MAKING R-F POWER SPEAK

You could run your r-f transmitter until the cows come home, yet the guy at the other end wouldn't have the slightest idea of what you had on your mind. You see, all he'd receive would be a sound of a certain single radio-frequency CARRIER WAVE. But if you modulate your carrier wave, he'd hear immediately what you were talking about.

#### AM AND FM

To start off—in figure 132 you see the wave-form of a carrier wave with a frequency of 1,000,000 cycles. One cycle equals 0.000001 second—one-millionth of a second. This wave is UNMODULATED—its strength or amplitude—*a*—is steady. You can MODULATE this wave by either of two general systems—AMPLITUDE modulation or FREQUENCY modulation. In one, you modulate the amplitude of the carrier at audio frequency; in the second, you leave the amplitude of the carrier constant, but vary the frequency

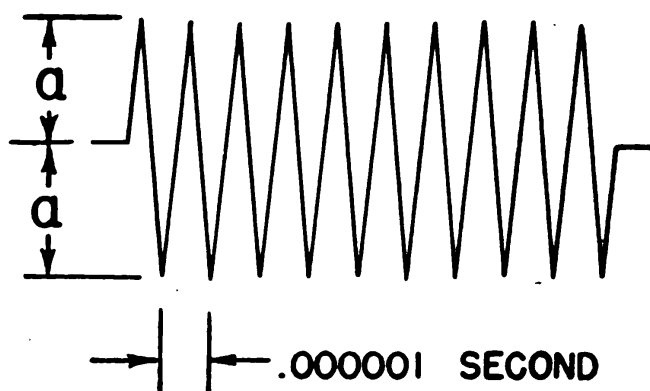


Figure 132.—Carrier wave.

in accord with the modulating frequency. Figure 133 shows these two types of modulation.

The most important advantage of *FM* over *AM* is the relative freedom with which static and similar noises can be eliminated in *FM* sets.

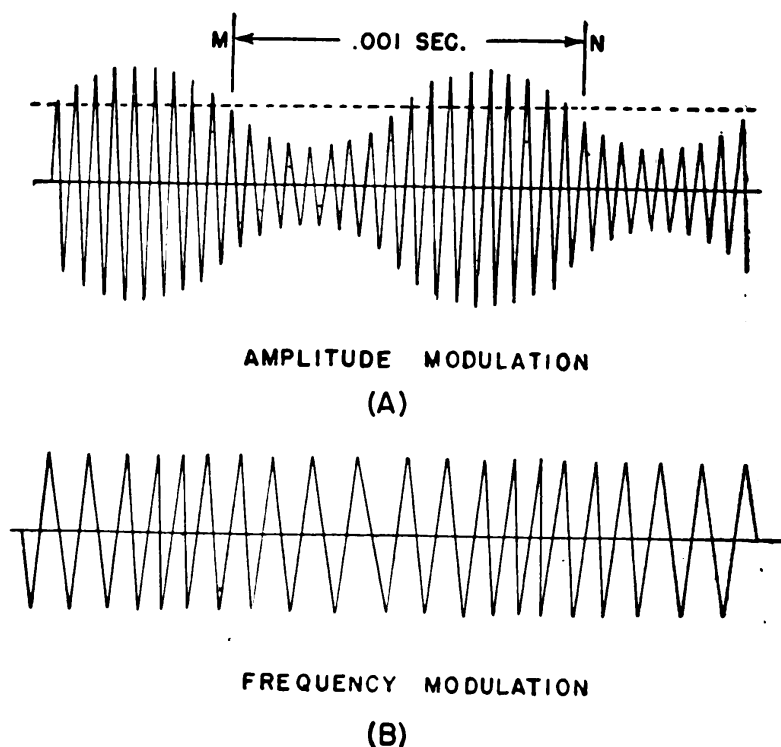


Figure 133.—Types of modulation.

## AMPLITUDE MODULATION

The simplest example of *AM* you'll hit consists of keying the carrier wave in a telegraph code of dots and dashes. Close the key and you get an amplitude-modulated carrier wave. Open the key, and the carrier wave drops to zero. This is OFF-ON modulation.

Another type of *AM* is MODULATED CONTINUOUS WAVE or MCW. Here the carrier wave is interrupted according to the code you're keying. And the carrier itself is modulated with an audio-frequency voltage. MCW graphs would look much like figure 133*A*, except for being broken up into code characters. This type of transmission can be received without using special circuits to make it audible. In contrast, a straight *CW* transmission would call for an oscillating detector or a beat-frequency oscillator at the receiver.

An INTERRUPTED CONTINUOUS WAVE—ICW—is also used occasionally for code transmissions. The carrier wave is keyed in the usual manner, but a CHOPPER is used to interrupt the carrier at an audible rate.

You can also have a SPEECH-MODULATED CARRIER. Here the carrier varies in AMPLITUDE with the intensity of a modulating frequency, and the wave form of alterations in carrier amplitude conforms to the wave form of the modulating frequency.

## STABILITY

In using AM, you must be careful that the application of modulation does not affect the carrier frequency, otherwise you'll develop DISTORTION. Also, since the signal channel is wider than the channel for a carrier of fixed frequency, you can easily interfere with other transmissions.

It's easier to maintain carrier stability by modu-

lating the POWER AMPLIFIER of the transmitter instead of the oscillator. In many transmitters, the RF oscillator is usually isolated from the oscillator by several intermediate stages, which are BUFFERS between the oscillator and the power amplifier.

In this type of circuit, the electrical constants and plate voltage of the oscillator remain fixed, and any

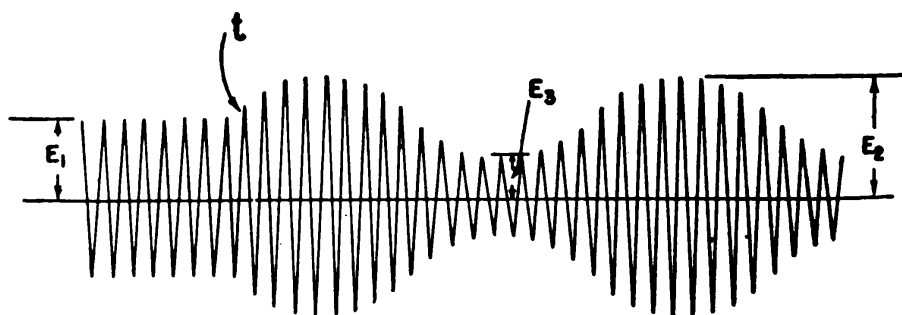


Figure 134.—50% modulated carrier wave.

frequency variation is held to a gradual shift in oscillator frequency. This shift is NOT caused by modulation.

You want MAXIMUM VARIATION of the carrier amplitude, since the AF voltage produced at the detector stage of the receiver is a function of the extent of variation of the carrier amplitude. Maximum variation occurs when the carrier is REDUCED TO ZERO and RAISED TO TWICE its value in one cycle of the modulating frequency. Under these conditions, the carrier is fully modulated. Full modulation is expressed as "100% modulation," and lesser degrees of modulation are percentages of full modulation.

Look at figure 134 to see what PERCENTAGE OF MODULATION means. In this diagram,  $E_1$  is the value of the UNMODULATED carrier. At time  $t$ , the carrier is being modulated with a sine-wave AF, and the amplitude of the carrier wave varies above and below the constant value  $E_1$ . The peak value is  $E_2$ ,

and the minimum value is  $E_3$ .  $E_2$  occurs only at the instant when the audio voltage reaches its peak value at a definite polarity, and the minimum value  $E_3$  occurs on the other alternation of audio voltage.

You find the PERCENTAGE MODULATION by

$$\% \text{ mod.} = \frac{(E_2 - E_1)}{E_1} 100$$

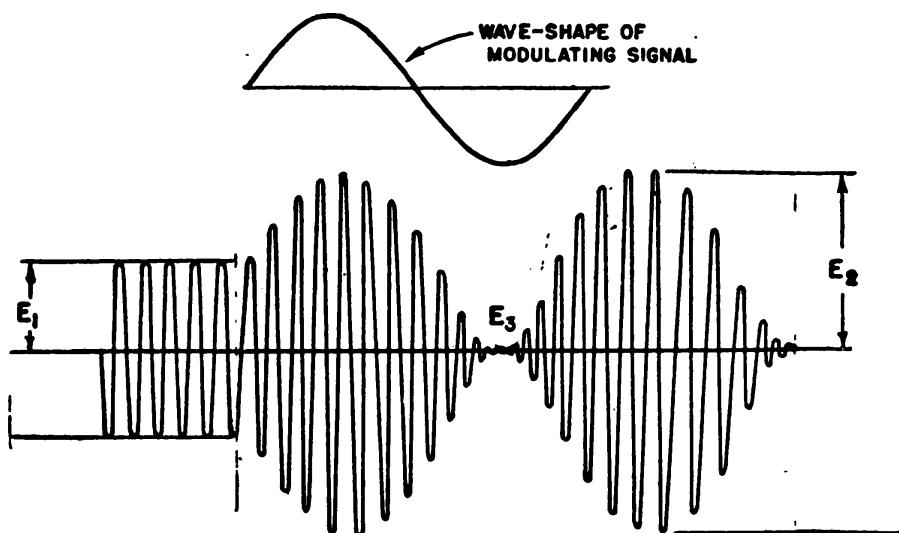


Figure 135.—100% modulated carrier wave.

In figure 135, you see a graph of 100% modulation. Here  $E_2$  has twice the value of  $E_1$  and  $E_3$  equals zero.

When you put on too much modulating power, you get a wave that looks like figure 136. Here the value of  $E_2$  is MORE THAN TWICE  $E_1$ , and there is a long gap of zero amplitude where  $E_3$  equals zero. The length of time of cut-off between opposite alternations of the audio voltage is proportional to the degree of over-modulation.

An over-modulated wave has a distorted component and has harmonics that were not present in the original a-f signal. Never modulate a carrier wave beyond 100%.

In these curves, the amplitude values are either for current or voltage, and the peaks represent the INSTANTANEOUS values. The resistance of the circuit usually remains constant, hence POWER varies as the

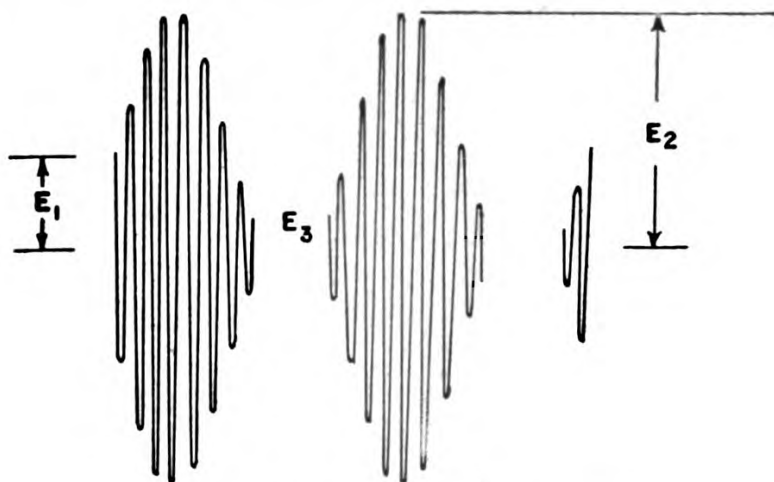


Figure 136.—Over-modulated carrier wave.

SQUARE of the CURRENT. For example, at the peak of modulation upswing for 100% modulation, the instantaneous power is four times as great as the unmodulated value. At the peak of the downswing, power is zero since the carrier current is zero. With SINE-WAVE modulation, average power in a 100% modulated wave is 50% greater than for its UNMODULATED value.

### PLATE MODULATION

PLATE MODULATION is the type of amplitude modulation that you'll run into most often. Here the audio voltage produced at the microphone is amplified in a speech amplifier. You use a power amplifier as a MODULATOR in the last stage of this amplifier, and couple the output of this stage in series with the B supply of an r-f power amplifier. You also feed the carrier voltage to the input of this amplifier, which usually operates as class C.

The r-f potential developed in the output circuit of the r-f amplifier is proportional to the plate voltage. The audio voltage is in series with this plate voltage, hence the EFFECTIVE voltage on the plate depends on the polarity of the audio voltage. A POSITIVE audio voltage ADDS to the plate voltage, and INCREASES the r-f output of the amplifier. A NEGATIVE audio voltage SUBTRACTS from the plate voltage, and LOWERS the effective voltage to the r-f plate, thus reducing carrier output. Result—carrier amplitude rises and drops at the same frequency as the audio voltage.

A diagram for plate modulation in a class C r-f amplifier is given in figure 137. You apply a HIGH

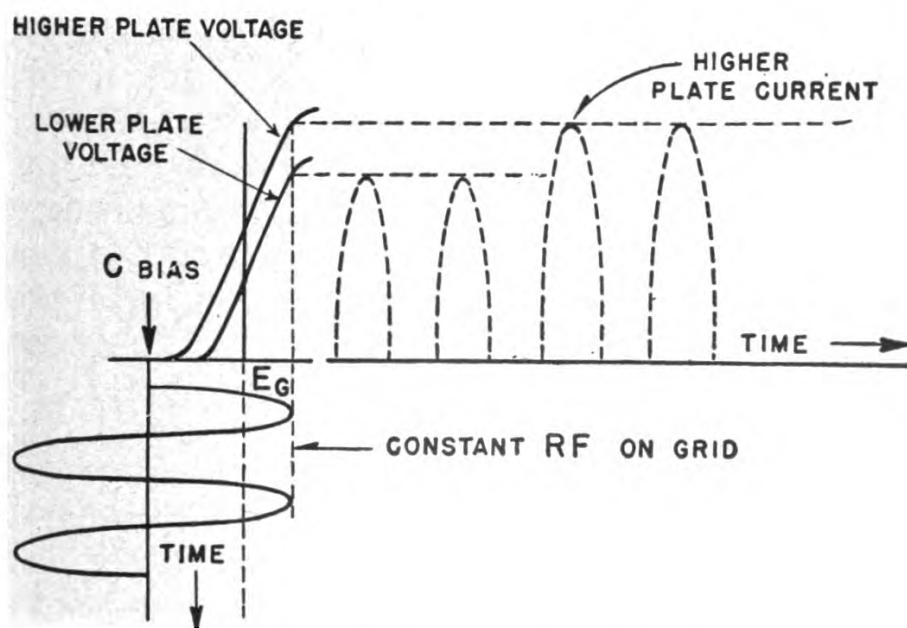


Figure 137.—Plate modulation in class C r-f amplifier.

exciter voltage to the grid circuit which is biased to more than twice the cut-off. The d-c plate current of the amplifier is a series of pulses. Since the resonant circuit of the plate has a flywheel effect, these pulses produce a sine-wave r-f current in the tank circuit. The maximum value of the r-f output



varies with the AMPLITUDE of these plate-current pulses. And these pulses in turn depend on the EFFECTIVE PLATE VOLTAGE. In figure 137, you have the relative amplitudes of plate current peaks for two values of plate voltages. The r-f output of the amplifier will follow the variations of effective plate voltages produced by the MODULATOR STAGE of the speech amplifier.

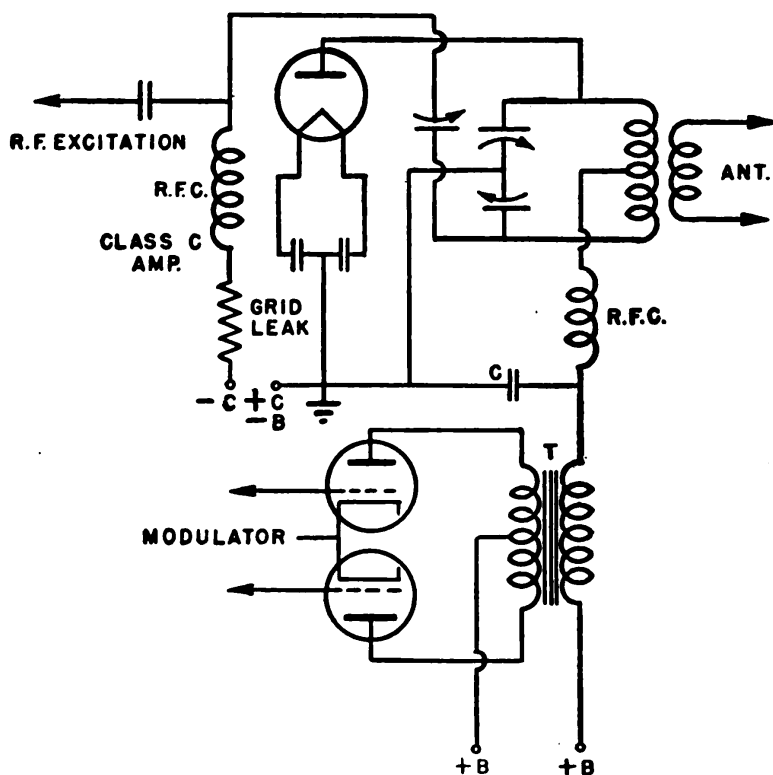


Figure 138.—Plate modulation circuit.

Figure 138 gives you the circuit for a typical class C PLATE-MODULATED r-f amplifier. In this circuit the a-f power is combined with the d-c power to the r-f amplifier plate circuit by a coupling transformer *T*. This is the most widely-used system of PLATE MODULATION. To get full modulation, you must pick the modulator audio output so that the EFFECTIVE plate voltage will vary between zero and two-times the d-c value. The AVERAGE power of the r-f amplifier

must rise 50% for full modulation, so AUDIO power equal to 50% of the d-c PLATE power must be supplied by the modulator stage.

### GRID-BIAS MODULATION

In this system of modulation, you apply the voltage developed by the modulator stage of the speech amplifier to the GRID CIRCUIT of the r-f amplifier. This amplifier operates as class C. The audio voltage developed varies the grid bias, and in turn varies the r-f power output.

In this system, PLATE VOLTAGE is CONSTANT, and you get the rise in power output with modulation by making the PLATE CURRENT and PLATE EFFICIENCY vary with the modulating signal. Since you get only about one-fourth the carrier output from a power amplifier tube that you'd get from the same tube with PLATE MODULATION, the GRID-BIAS MODULATION system isn't used very widely. The only advantage of grid-bias modulation is that you can use a LOW-POWER MODULATOR, since it needs only to supply the power lost by connection to the r-f amplifier grid circuit.

### OTHER MODULATION

Two other systems are SUPPRESSOR and CATHODE MODULATIONS.

You produce SUPPRESSOR MODULATION by varying the bias on the suppressor grid of a pentode r-f amplifier that is operating as class C. This system is similar in principle to grid-bias modulation, but the r-f excitation and modulating signals are applied to separate grids. This makes the system easier to adjust. Carrier efficiency is about the same as for grid-bias modulation, and the modulator power needed is also small.

To produce CATHODE MODULATION, you apply the audio power to the CATHODE circuit of a class C r-f

amplifier. Thus, both GRID BIAS and PLATE VOLTAGE vary during the modulation cycle. This system is a combination of grid bias and plate modulation systems. CATHODE MODULATION does not give as good r-f efficiency as plate modulation, but gives much better r-f efficiency than grid-bias modulation.

## SIDEBANDS

To combine a.f. and the r-f carrier is basically a HETERODYNE process. Hence, you'll get beat frequencies equal to the sum and the difference of the a-f and r-f bands involved. Or, for each AUDIO frequency that appears in the modulating signal, you get TWO NEW radio frequencies. One of these is equal to the CARRIER FREQUENCY PLUS THE MODULATION FREQUENCY. The second is equal to the CARRIER FREQUENCY MINUS THE AUDIO FREQUENCY. Since these new frequencies are off to either side of the carrier, you call them SIDE FREQUENCIES. The group of SIDE frequencies covering a BAND of modulation frequencies are called SIDEBANDS. So—

A modulated signal covers a GROUP of frequencies, or channels, rather than a single frequency, as would be the case with an UNMODULATED carrier.

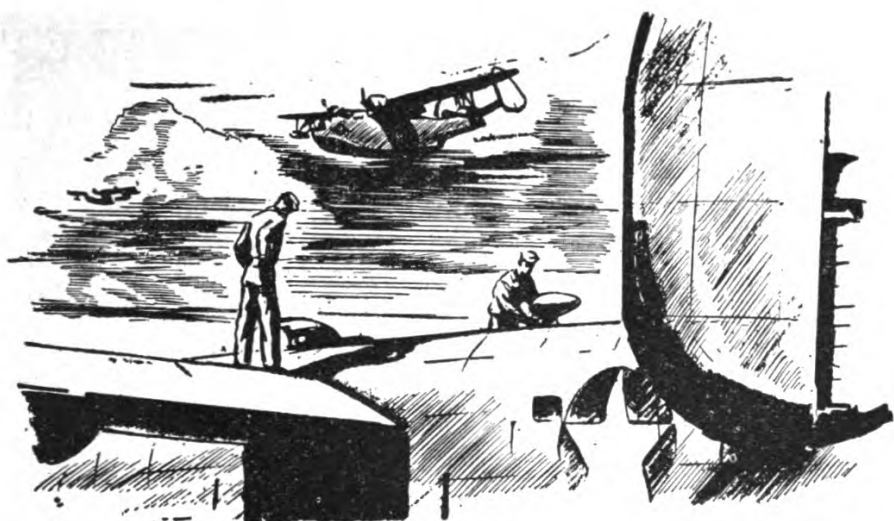
Since these sidebands are on either side of the UNMODULATED carrier, the channel WIDTH needed to contain the MODULATED signal has to be TWICE as wide as the highest modulating frequency. For example—you modulate a 1,000,000-cycle r-f signal with a 1,000-cycle AUDIO signal. So, your channel width will be from 999,000 cycles to 1,001,000 cycles, or 2,000 cycles.

## POWER

There are TWO components to power in a modulated wave—the power in the CARRIER WAVE, and the power in the SIDEBANDS.

For 100% modulation, you must make the maximum amplitude of the modulated wave TWICE that of the carrier wave. So, each sideband must contain one-fourth the total power output, since the TOTAL power contained in the wave is equal to the SUM of the carrier wave PLUS the two SIDEBANDS. Result—the total power output at 100% modulation must be  $1\frac{1}{2}$  times the power in the unmodulated carrier wave. Therefore the power output is increased 50% by modulation.





## CHAPTER 9

# WAVES AND ANTENNAS

Now that you've put your voice into the microphone, have run it through the a-f and r-f amplifiers, you're ready to feed it to the antenna and throw it out as waves to be picked up by some receiver miles away. First, you ought to know what radio waves are like and how they act.

## RADIO WAVES

Radio waves are ELECTROMAGNETIC waves, composed of traveling electrostatic and electromagnetic fields related to each other in such a way that the energy is divided evenly between the two. The lines of force of the two fields are at right angles to each other in a plane perpendicular to the direction of broadcast. Radio waves act just like light waves, move at the same speed as light, and can be reflected, refracted, and diffracted. The only difference between light and radio waves is the wave lengths of the two.

Radio waves can be REFLECTED from any object that normally would reflect light, heat, or other types of waves. The surface of the earth is a good reflector of radio waves.

A change in the density of air or a change in temperature, pressure, or humidity will produce REFRACTION or BENDING of the radio wave. For this reason, the atmosphere tends to bend the radio waves back toward the earth. Refracted radio signals are not as stable as direct radio waves, since the atmospheric conditions that cause refraction are not stable. Fading results from refracted signals.

When a radio wave grazes the edge of an object in passing, the wave is bent or DIFFRACTED.

A transmitter gives out two types of waves—a SKY wave and a GROUND wave.

### GROUND WAVE

This wave travels in continuous contact with the surface of the earth, and induces a current in the earth as it travels over the surface. Over long distances, where the curvature of the earth becomes large, ground waves are DIFFRACTED to follow the curved surface of the earth. There is also some REFRACTION of these waves by the atmosphere at the earth's surface. Ground waves are highly stable, and are not affected by seasonal and day-and-night effects at frequencies above 1,500 kc.

Since the earth has a fair amount of electrical resistance, current flow induced by the ground wave shows high losses, which must be replaced by the wave. This causes weakening of the ground wave, and affects the transmitting range. Sea water is a better conductor than earth, so the range will be greater over water. Losses of energy in the ground wave increase rapidly as frequency increases, and at frequencies above 3 megacycles, ground waves are useful only for local transmissions.

### THE IONOSPHERE

The IONOSPHERE is a region in the upper atmosphere or heavens where a belt of free electrons and

ions have collected in sufficient concentration to repel the radio sky waves back to the earth. It is because of these layers in the ionosphere that radio waves from an antenna don't go shooting off into space to be lost forever. Figure 139 shows you a portion of a slice through the earth, atmosphere, and ionosphere.

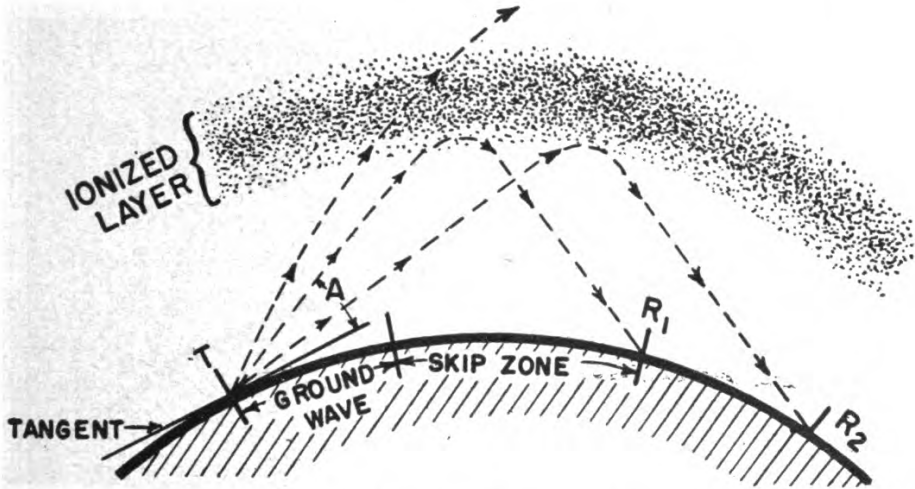


Figure 139.—Slice through earth, atmopshere, and ionosphere, to show refraction of sky waves.

The reflection of the sky wave is carried out at any angle, depending on the frequency of the wave. Bending is less with high-frequency waves, and a larger portion of the h-f waves penetrate the ionosphere. As a result, at very high frequencies, long-distance radio transmission becomes impossible.

And, as ionization varies with the activity of the sun's radiation, the REFLECTION of sky waves varies, causing variations in the range of radio transmission.

### CRITICAL FREQUENCY

If you emit LOW-FREQUENCY waves from an antenna, they will bounce off the ionosphere and return vertically back to the transmitter location. Keep increasing the frequency of the waves for a given ionization of the ionosphere, and you'll reach a frequency at which the sky wave breaks on through



the ionosphere and does not return to the surface. THAT is the CRITICAL frequency, and you can use it as a guide or index to transmitter conditions at a given period. Usually the maximum USABLE frequency for waves transmitted at small angles above ground is about THREE TIMES the CRITICAL frequency.

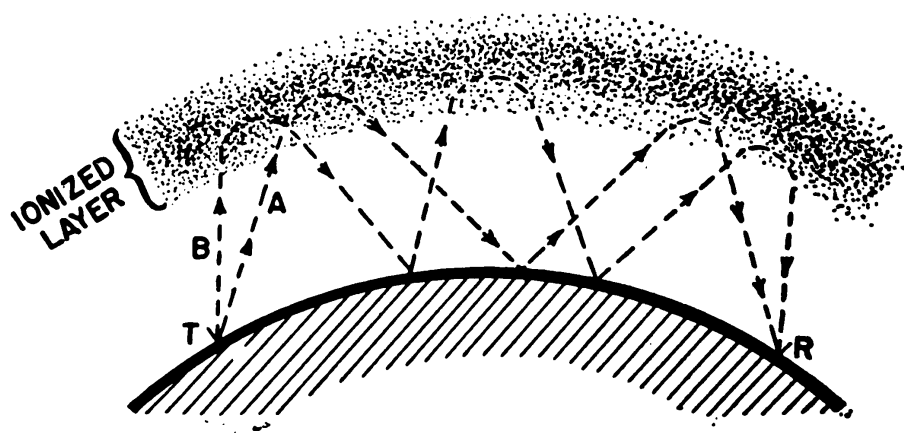


Figure 140.—Multi-hop transmission.

After your sky wave has bounced back to earth from the ionosphere, it may be reflected by the earth back to the ionosphere, and so on to a distant point on the earth. This is MULTI-HOP, and the distance between earth bounces that is not covered by the ground wave is the SKIP-DISTANCE. In figure 140, you see a diagram of MULTI-HOP and SKIP-DISTANCE.

### FADING

Frequently two or more parts of a wave may follow slightly different paths in traveling from the transmitter to the receiver, as in figure 140. The difference in the lengths of the paths will make a difference in phase between the parts at the receiver. The field strength of the signals can thus have any value between MAXIMUM, when all components are in phase, and ZERO, when there are only two components and they are exactly OUT of phase.

Since the paths change and vary, you get a wide variation in signal strength, called **FADING**. Fading can also be caused by variations in the ionosphere which cause the receiver to lie just outside a skip zone. Since variations in the ionosphere are greatest when the sun is close to the earth, fading and electronic noises are greater at those seasons.

### VERY-HIGH-FREQUENCY WAVES

When you're handling the very high-frequency waves, above 30 megacycles, you run into slightly different conditions. Radio energy of the v-h-f wavelengths is transmitted mostly by a **DIRECT RAY** or wave traveling in a straight line. The bending of the sky waves in the ionosphere is so slight that the effect of the sky wave on this frequency range is almost negligible. And at these v-h-f ranges, the ground wave is practically absorbed by the earth. Hence—

Maximum signal strength at v-h-f's can be obtained only when there is an unobstructed atmospheric path between the transmitter and receiver. The **HEIGHT** needed to provide a **LINE OF SIGHT** from an elevated transmitter point to surface receiver is approximately

$$h = \frac{d^2}{1.51}$$

where  $h$  is the height of the antenna in feed, and  $d$  is the distance from transmitter. Conversely, the **DISTANCE** in line-of-sight transmission that you can get with a v-h-f transmitter and an antenna of **HEIGHT**  $h$  is gotten by the formula

$$d = 1.22 \sqrt{h}$$

The **RADIO HORIZON**  $d$  is greater than the **VISUAL HORIZON** because the radio waves tend to follow the curve of the earth to a slight extent.

By applying these formulas to the transmitter **AND**

the receiver, and adding the results, you'll get the distance over which you can transmit by v-h-f radio. Sometimes the ACTUAL range of v-h-f radio is greater than the CALCULATED range because of increased refraction near the ground due to a layer of warm air on top of the colder ground-surface air.

V-h-f radio waves are used in television and similar modifications of radio.

## ANTENNAS

There's a lot more to designing and installing an antenna for a transmitter than shinnying your way to the top of the garage and running a wire to the house. An effective antenna system is designed for a specific type of transmitter on a specific frequency. An antenna that works fine with one frequency may not work at all well with another frequency. In designing an antenna, you must consider its POLARIZATION, ANGLE OF RADIATION, IMPEDANCE, and DIRECTIVITY.

Of course, the antenna system of an aircraft is designed and fitted into that particular aircraft, but you may be called on to set up an antenna system at your ground station. And to repeat, you can't shinny up the roof of the hanger, toss a wire over to the administration building, and pat yourself on the back for installing a good transmitter antenna.

## POLARIZATION

The position of an antenna with respect to the earth gives you its POLARIZATION. Or, a VERTICAL antenna sends out VERTICALLY polarized waves, while a HORIZONTAL conductor emits horizontally polarized waves. A SLANTING antenna sends out waves that are a combination of both.

## ANGLE OF RADIATION

The ANGLE OF RADIATION is the wave angle at which an antenna radiates best, and is determined by the POLARIZATION and HEIGHT above ground of the antenna, and the nature of the earth. This angle is measured up from ground level, and is marked "A" on figure 139.

## IMPEDANCE

The ratio of VOLTAGE to CURRENT at any particular point along the length of an antenna gives you its IMPEDANCE at that point. The impedance is the actual LOAD RESISTANCE of the antenna to the POWER APPLIED.

## DIRECTIVITY

An antenna usually radiates better in some directions than in others. This feature is directivity.

## CURRENT

The CURRENT in an antenna produces an electromagnetic field around the conductor that is proportional to the current. The portion of the wire which carries the largest current will have the largest radiating effect.

## STANDING WAVES

If you start an electrical impulse out along a wire, it will travel at the speed of light to the end of the wire. If the wire is open-circuited, the impulse will be reflected at the end of the wire, and will travel BACK.

Now apply a high-frequency a-c voltage to the wire. Waves of current will travel out along the wire, and be reflected back in a continuous cycle. Suppose you choose a wire long enough so that approximately a half-cycle of time passes while a

current wave travels to the end of the wire. Then the outgoing wave and the reflected wave will have varying phase relations such that at one point the two waves will be  $90^\circ$  out of phase, and at another they will be in phase, with varying degrees of phase angles in between.

If you ignore the small losses, you can say that the RESULTANT of these currents will vary in amplitude between zero and maximum along the wire. This variation is called a STANDING WAVE.

The voltage likewise goes through standing waves that are  $180^\circ$  out of phase with the current standing wave.

If you made the antenna resonant to the frequency of the current applied, the currents of the original and the reflected waves would combine at the center of the antenna and would reach zero together at the ends. Thus, you'd have a maximum voltage induced by the waves at the ends, and a minimum voltage in the center. This gives you efficient radiation.

To get maximum radiation, your antenna should be resonant to the transmitter frequency. This resonance occurs when the antenna has STANDING WAVES. If the antenna lacks standing waves, it's out of resonance, and is operating below maximum radiation efficiency.

### HALF-WAVE ANTENNA

A HALF-WAVE ANTENNA has a length approximately one-half that of the transmitting wave length. This type is also called the HERTZ antenna.

These antennas fall into two types, ELEVATED or GROUNDED.

An ELEVATED antenna operates at some distance from the ground or earth, and can be either horizontal or vertical.

A GROUNDED antenna has one end grounded through the OUTPUT of the transformer, or through

the lower end of the coupling coil. Grounded antennas are used in such installations as aboard aircraft, where the aircraft structure acts as the ground.

ELEVATED antennas are usually used on HIGH frequencies above about 2 megacycles. GROUNDED antennas are used BELOW that frequency, since these lower frequencies produce long waves requiring a long antenna to give efficient radiation.

Suppose you have a frequency of 1,000 kc. A half wave-length would require 500 feet of antenna, which would present quite a stringing problem. So, by using antenna inductance loading, you can use a QUARTER-WAVE antenna, or sometimes an even shorter antenna. You can connect the transformer output to the CENTER of the antenna; you'll find that the center of the antenna is the point of maximum current.

You can use the ground as one-half of the half-wave antenna, using the actual antenna as the other half. Thus the antenna-half is only one-quarter wave long. Under these conditions, the antenna radiation has the characteristics of those of a half-wave antenna, except that antenna radiation resistance is half that of a half-wave antenna. This quarter-wave radiator is called the MARCONI ANTENNA.

ANTENNA INDUCTANCE COILS are usually installed on transmitters to compensate for the shift of  $LC$  values of antennas as frequencies are changed. You must always fit the antenna to the particular wave length you're using, in order to get efficient radiation of the signal. When you shift the  $LC$  values by means of the antenna inductance coils, you are IN EFFECT changing the over-all length of the antenna to fit the selected frequency.

You can calculate the length of a HALF-WAVE ANTENNA by using the formula

$$L = \frac{468}{f}$$

where  $L$  is the LENGTH, and  $f$  is the selected FREQUENCY, in megacycles. This formula is good for frequencies up to 30 Mc.

The RADIATION RESISTANCE of a HALF-WAVE antenna, in free space and measured at the CENTER, where current is maximum, is about 73 ohms. As you move the antenna towards the earth, energy reflected from the earth sets up voltages in the antenna, causing changes in the radiation resistance. If you measure the radiation resistance of this antenna, in free space, and at one END, you'll find the resistance to be about 2,400 ohms. Other losses, such as insulator leakage and ohmic resistance, represent about 5 percent of the total power put into the antenna.

You can mount a half-wave antenna either horizontally or vertically. Mount it vertically, and it will radiate equally well in EVERY direction. But mount it horizontally, and it radiates best in directions at right angles to the antenna. This HERTZ antenna can be operated at its FUNDAMENTAL frequency or any of its HARMONIC frequencies.

But if you use MORE than a half-wave length of antenna, the radiations are broken up into weaker radiations that are scattered in various directions.

### POWERING THE ANTENNA

You can apply power to the antenna either DIRECTLY or INDIRECTLY. If the power from the transmitter goes straight to the antenna, you have a DIRECT-EXCITED antenna. This system is used only on low-frequency amateur stations.

The most satisfactory method of coupling the transmitter and the antenna is by TRANSMISSION LINES, since you can place the antenna at a suitable distance from the transmitter.

If you feed the transmitter output to the spot on the antenna where the CURRENT is MAXIMUM, you

have a CURRENT-FED ANTENNA. Feed the output to the point of MAXIMUM VOLTAGE, and you have a VOLTAGE-FED ANTENNA.

## TRANSMISSION LINES

In using TRANSMISSION or FEEDER lines to carry energy from the transmitter to the antenna, you must avoid RADIATION from these lines. Radiation may cause loss of power, or produce fields that affect the desired directivity of transmission.

Also, you must keep transmission-line impedance low in order to save radio energy. Here's how you can have a RESONANT circuit that also has LOW impedance—

If you were to fold a HERTZ half-wave antenna in the middle, you'd get a pair of quarter-wave wires in which the fields would be equal and opposite for their entire length. The fields cancel out and eliminate any radiations from the transmission line. This forms a RESONANT transmission line. With a HERTZ HALF-WAVE ANTENNA, you can make the effective length of the transmission any multiple of the QUARTER-WAVE length. But with a QUARTER-WAVE MARCONI ANTENNA, you'd use ONLY the ODD multiples—3, 5, 7, etc.—of the QUARTER-WAVE length.

A RESONANT TRANSMISSION LINE must be a DEFINITE length, and also has standing waves all along it which cause loss of energy into nearby objects. Here's how you fix THAT—

Connect an impedance across the two lengths of your transmission lines. You can now divide your line into any reasonable lengths according to the value of impedance at the end of each length. You can be sure that you've gotten rid of the standing waves by moving an electric light bulb attached to a loop of wire up and down the transmission line. The bulb will light when it's absorbing standing waves.



Adjust the impedance until the bulb does not light up anywhere along the transmission line. Then your line is NON-RESONANT.

### LOADING

In aviation radio, you must use one antenna for transmitting radio signals of various frequencies. Sometimes you can reel the antenna in and out to fit the particular frequency you're using. But this isn't always practicable. You can get the same result by putting an inductor or condenser in series with the antenna. For example—

Your antenna is too short for the desired frequency. In other words, the natural frequency of the antenna is greater than that of the transmitted signal frequency. Insert an inductor in series with the antenna, and the total inductance of the antenna becomes greater. This increased inductance cuts down the natural frequency of the antenna. If you use a VARIABLE inductor, you can readily adjust the antenna frequency to the transmitter frequency.

To take care of cases where the antenna frequency is too small, insert a VARIABLE CONDENSER in series with the antenna. By tuning the condenser, you reduce the over-all capacity in the antenna and increase the natural frequency of the antenna to fit the transmitter frequency.

This process of varying antenna length by electrical means is LOADING.



## CHAPTER 10

### RECEIVERS

#### KEEPING HOPE OUT OF GRAND OPERA

Your radio receiver has three jobs to do—SELECTION, DETECTION, and AMPLIFICATION. The SELECTOR department takes care of giving you Bob Hope and keeping out “La Boheme”—provided, naturally, that you WANT Bob. Of course, if you’re a long-hair and want “La Boheme,” you can have it by tuning the selector. And the AMPLIFIER pushes Hope up high enough for you and everybody in the county to hear. Then the DETECTOR separates the audio signal from the r-f CARRIER WAVE that transports it.

#### DETECTORS

An ideal detector will give you an output wave which exactly reproduces the wave that was picked up by the antenna and passed on to the detector input. If the detector does anything to change the input wave form, you’ll get a distorted Hope or “La

Boheme" to feed the amplifier section. And this distortion can be either AMPLITUDE, FREQUENCY, or PHASE DISTORTION.

In figure 141 you see a sketch of an r-f signal. The wave is unmodulated between points *R* and *S*. In the

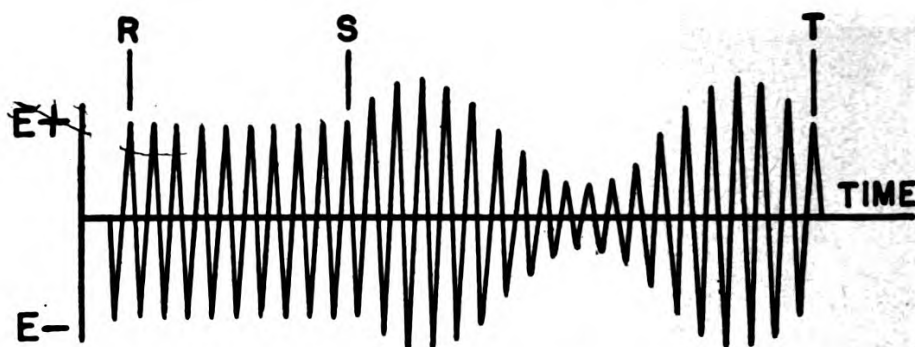


Figure 141.—R-F signal, unmodulated and modulated.

section *S-T*, the amplitude of the wave is varied in harmony with the a-f wave of the transmitter. For instance, Hope may have started telling a story at point *S*. You remember how a RECTIFIER works. If an a-c voltage is put across a rectifier, you'll get a

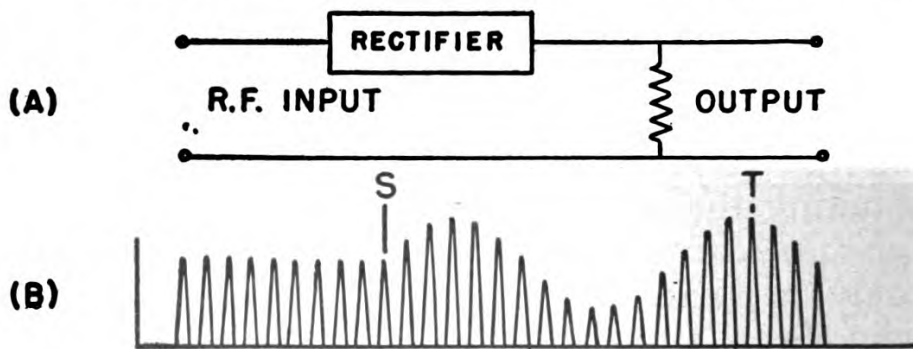


Figure 142.—Rectifying r-f a-c wave.

pulsating d.c. output. So put the r-f input a-c wave of figure 141 through a rectifier, figure 142*A*, and you'll yet out the rectified d-c wave of figure 142*B*, which pulsates at the same radio frequency as the original input a-c wave. This is the first step in DETECTION.

Next you must FILTER this rectified r-f, d-c signal. Run it through the circuit of figure 143A. The condenser  $C$  will by-pass or FILTER out the r-f pulses, and produce an a-f PULSATING d-c voltage across resistor  $R$ . This voltage varies in magnitude with the a.f. used to modulate the carrier wave. When you put the unmodulated part of the signal across

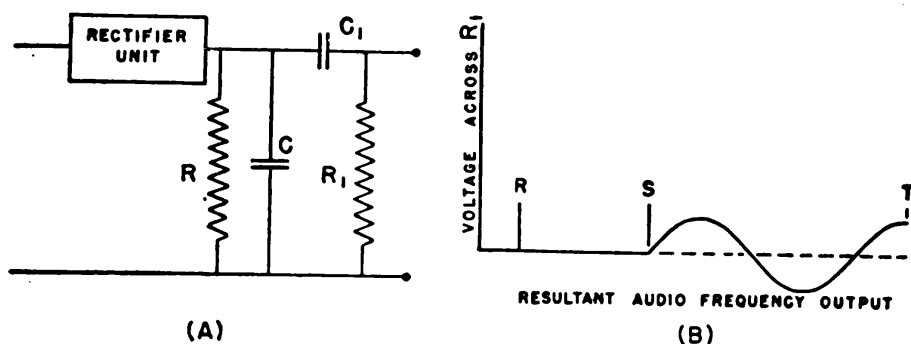


Figure 143.—Detector filter and coupling circuit.

the filter, you get a constant voltage across resistance  $R$ . This voltage is an  $IR$  drop and equal in magnitude to the product of resistor  $R$  and the average value of current produced by the half-wave rectifier. The condenser tends to keep this voltage constant by discharging during the interval between peaks of the r-f voltage.

Between points  $S$  and  $T$ , your input signal is modulated, and the rectifier output voltage will vary with this audio modulation. This varying output voltage produces a pulsating d.c. through  $R$ , and this current in turn produced a pulsating d-c VOLTAGE across  $R$ . And your ear-phones are made to turn out sounds by this pulsating d-c voltage. But actually this voltage is too small to operate reproducers, such as loudspeakers, requiring large power.

The a-c portion of this pulsating d-c voltage produces an a-c current in the circuit  $C_1$  and  $R_1$ . The voltage produced across  $R_1$  by this current is a-c

voltage with the same frequency as the modulation on the carrier wave. You have a graph of this voltage in figure 143B.

### DIODE DETECTOR

This is just about the simplest and most-used detector. You see the circuit diagram for the DIODE DETECTOR in figure 144.

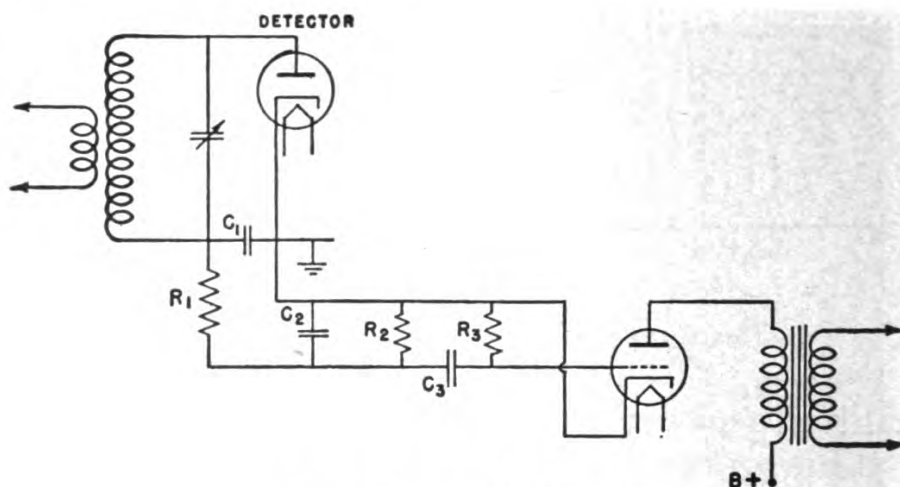


Figure 144.—Diode detector.

Current flows through the diode in this circuit only when the plate is positive. This rectifies the r-f input voltage. The filter circuit is made up of the condenser  $C_1$  and the resistor  $R_1$ , and the action of this filter circuit is exactly like that of the detector circuit you've already learned. But—

The diode detector has one disadvantage—it loads the tuned circuit, and reduces the selectivity of that stage.

In this circuit of figure 144, you also have the connection between the detector and the audio amplifier. In this case it's a resistance-capacitance coupling. The signal applied to the amplifier grid is an a-c voltage with a frequency equal to the modulation envelope of the r-f carrier wave.

You work your diode detectors at very high load resistances—up to 1 megohm. You can often use a triode or pentode that has a built-in diode section to avoid having to put in a separate diode. You can also make a triode operate as a diode by connecting the grid and plate together.

### PLATE DETECTOR

The circuit for a PLATE DETECTOR is shown in figure 145*A*. This detector works with the bias set at the CUT-OFF POINT. Thus, you eliminate the negative half of the carrier, and you make the plate current a series of pulses. These plate current pulses produce a d-c voltage across the load resistor. This d-c voltage

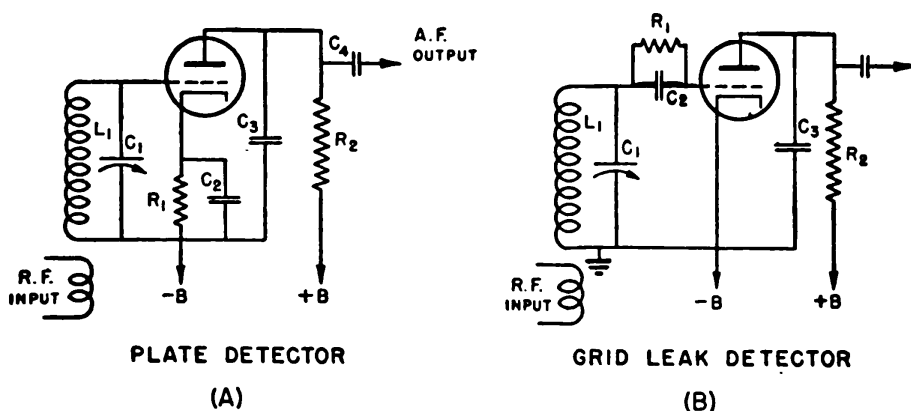


Figure 145.—Detector circuits.

pulsates at the frequency of modulation. The filter condenser by-passes or filters out the r-f pulses to produce an a-f pulsating d.c.

There are two general types of plate detectors—SQUARE-LAW and LINEAR. The SQUARE-LAW detector develops an output that is proportional to the SQUARE of the amplitude, and signal swings over the curved portion of the plate characteristic curve. Rectification in this section of the curve causes distortion, and so the square-law detector is seldom used except for weak-signal detection.

In the linear detector the rectified output is proportional to the amplitude of the input voltage. Bias is at cut-off, but the signal amplitude is such that the entire length of the characteristic curve is used. Distortion at the curved portion of the characteristic curve is rather small when the full length of the curve is used.

### GRID-LEAK DETECTOR

In the GRID-LEAK DETECTOR, the carrier wave is rectified in the grid circuit. You see the circuit diagram in figure 145B. When there is no signal on the grid, grid bias is zero, and plate current is relatively high. But put the carrier signal on the grid, and the positive alternations of the carrier drive the grid positive. Now the grid draws current as a series of pulses through the grid leak. This develops a voltage across the grid leak. And your circuit is now equivalent to the simple diode detector. The grid condenser corresponds to the filter condenser. The d-c voltage across this condenser pulsates at the modulation frequency of the carrier voltage to reproduce the original signal voltage.

The polarity of the voltage across the condenser acts to bias the grid negatively. And increases in r-f potential over the modulating cycle increase the negative grid bias. Similarly, the negative bias drops off as the r-f potential decreases over the same cycle. You see what happens—PLATE CURRENT DROPS on the modulation UP-swing, and RISES on the DOWN-swing.

Grid-leak detectors have high sensitivity and good fidelity for small input voltages. But distortion increases as the carrier amplitude increases. This type of detector also loads the tuned circuit in the same way as the diode detector does, resulting in lowered selectivity. Hence you'll find the grid-leak detector used much less than either the diode or linear plate detectors.

## REGENERATIVE RECEIVER

The SIMPLEST receiver would be made up of an antenna, a tuned circuit, a detector-rectifier, and a pair of phones. With it, you could receive modulated carrier waves from nearby powerful transmitters. But the sensitivity and selectivity would be poor, and you wouldn't be able to cut-out adjacent frequencies. So—

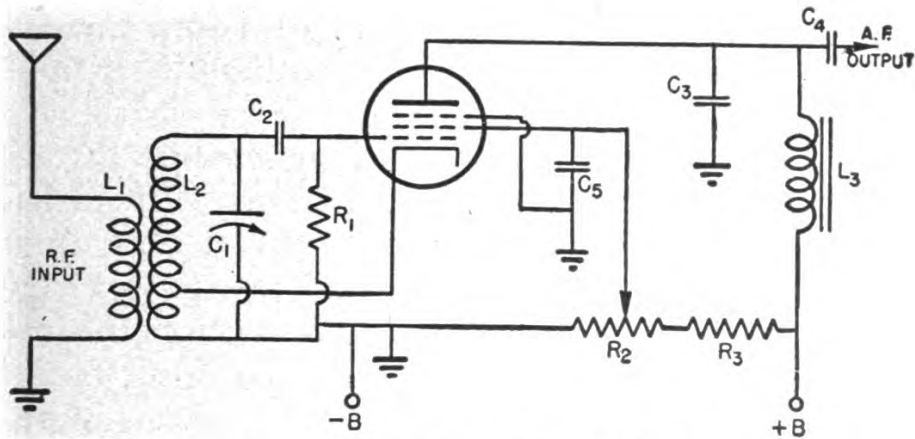


Figure 146.—Regenerative detector.

For PRACTICAL purposes, the simplest type is a REGENERATIVE RECEIVER.

In the regenerative receiver, you feed the plate-circuit energy at signal frequency back to the grid circuit to reinforce the original signal amplitude. In this way, you increase the SENSITIVITY of the receiver, and also increase its SELECTIVITY. What's more, this regenerative amplification occurs only at the frequencies to which the circuit is tuned. Since the circuit acts as a combination amplifier—and—detector, you'll use the most sensitive type of detector—a GRID-LEAK DETECTOR.

You have the circuit diagram for a regenerative detector in figure 146. Actually it's a combination of a detector and a Hartley oscillator, with a feedback control. You use the cathode tap to feed back energy at signal frequency to the grid circuit. By



varying the screen voltage, which varies the amplification of the tube, you control this feed-back. By adjusting the screen control to a voltage just below the oscillation point of the circuit, you give the input signals maximum amplification.

The plate load in this circuit is a reactor with high impedance at audio frequencies. The coupling condenser  $C_4$  feeds the output to additional stages of audio amplification. You can also put a pair of phones across the output with no audio amplification. Leave out the plate impedance and hook the phones directly in the plate circuit.

You can also use triodes in regenerative circuits, but you must use some other method of feed-back control. The best control is a TICKLER COIL in the plate circuit. Couple this coil to the grid circuit, then you control the feed-back by varying the position and relative angle of the coil. In other circuits you can use a variable condenser in series with a fixed tickler coil.

The regenerative circuit also enables you to receive straight *CW* signals. To do this, you adjust the control to allow the tube to work both as a detector and as an oscillator. When in oscillation, the tube frequency is adjusted by the tuning condenser to set up a difference frequency between the signal and the receiver oscillator. Adjust the oscillator frequency to get an AUDIBLE frequency difference. HETERODYNE ACTION will make this difference show up in the plate circuit, and you can amplify it more or put it directly on the phones.

You should carefully choose the electrical constants of a regenerative set to obtain the best operation. Here are things to watch for—

The control should enable the circuit to go into regeneration smoothly and without a click. The amount and kind of coupling decide this point.

Next—

Your receiver should be capable of oscillating over its entire band. Resonant effects of the antenna cause a difference in the amount of regeneration at each portion of the band. So the antenna coupling is the critical factor in obtaining smooth control at the oscillation point. If you encounter dead spots, they are usually due to improper antenna coupling.

### SUPER-REGENERATION

Maximum amplification of the signal occurs at a point just below oscillation. By using a SUPER-

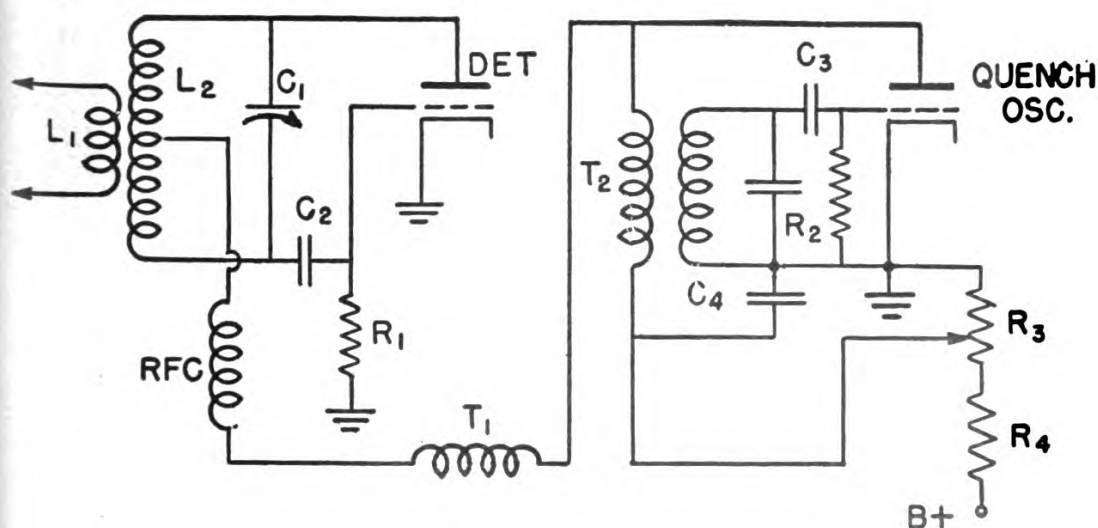


Figure 147.—Super-regenerative circuit.

REGENERATIVE circuit you can approach this maximum point more closely without letting the tube to break over into oscillation. You make a super-regenerative circuit by adding a QUENCH or INTERRUPTION FREQUENCY to the PLATE circuit. This quench frequency is above the audio range—about 20 to 100 kilocycles. Putting in this quench frequency in effect varies the detector operating point, allows you to greatly increase regeneration and build up the signal to high proportions. This type of circuit, shown in figure 147, is suitable only for

receiving modulated transmissions, and is much used on high-frequency receivers.

Here's what happens in the circuit of figure 147. You lead the quench frequency from the separate quench oscillator to the plate circuit. This oscillating a-c voltage introduced into the detector circuit varies the operating point of the detector. Thus the detector can oscillate only when the varying operating point is in a region suitable for oscillations.

### TUNED R-F RECEIVERS

In the TUNED R-F (T-R-F) receiver, you raise the signal to a relatively high level by amplification at the signal frequency. This usually calls for several r-f amplifier stages in tandem, with each stage tuned to the same frequency. To cover a certain band of frequencies, you tune the stages by variable condensers gang-mounted on one shaft. Tetrodes and pentodes are used because of the internal shielding provided by the screen grid. Thus, you don't need to neutralize the stage to prevent oscillation from feed-back through interelectrode capacities.

You see the circuit diagram for a typical stage of T-R-F amplification in figure 148. You'd operate this stage as class A in a receiver. You eliminated feed-back by using the screen-grid tube, but you'll still have to shield the output from the input by putting grounded shields around the tuned circuit, and by keeping the plate and grid leads well apart.

Use either inductive or capacitive coupling, or a combination of both, from the plate circuit of one stage to the grid circuit of the next. In figure 148 both are used. The single-open-ended turn from the high side of the grid to the high side of the plate acts as a small condenser. You use combination couplings of this type to maintain a desired coupling ratio across the amplifier frequency band.

You determine the value of  $L_1$  by the particular

frequency band you want to cover, and you use the variable condenser  $C_2$  to adjust the amplifier for operation at any point WITHIN the selected frequency band. Make the ratio of  $L_1$  to  $C_1$  as high as possible to obtain desired selectivity. Choose the type of coupling between primary and secondary by the type of transmission to be received. For straight CW

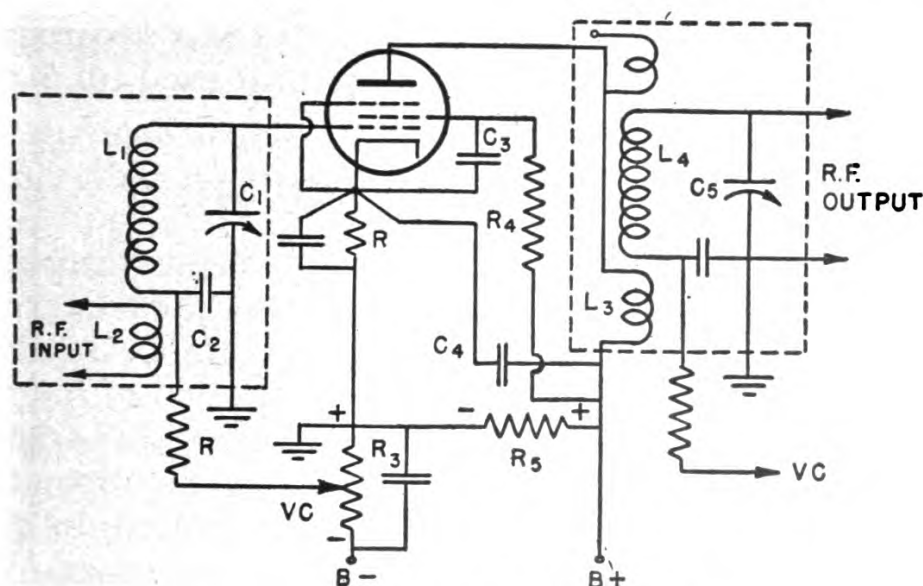


Figure 148.—Single-stage T-R-F amplifier.

signals you need very high selectivity. To receive voice, you must make a compromise in order to amplify a band of frequencies on either side of the tuned frequency, hence your coupling must be HIGHER than the most satisfactory value if you want uniform response at high frequencies.

### GAIN CONTROL

You can adjust your receiver to the desired sound output by varying the over-all amplification. In an a-f amplifier, the amplifier gain remains constant and the INPUT VOLTAGE IS ADJUSTED to get the desired output voltage. But in an r-f amplifier, you vary the GAIN OF THE AMPLIFIER and leave the input voltage to the amplifier as it is.

There are several ways for you to control r-f amplifier gain. One method is by simultaneously varying the d-c VOLTAGE on the SCREEN GRIDS of all the amplifier stages. With VARIABLE  $\mu$  TUBES, the best practice is to vary the CONTROL GRID BIAS of all amplifiers at the same time.

Look at figure 148 again. In this circuit, you vary the control grid bias by adjusting potentiometer  $R_s$ . Any increase in negative bias produces a reduction in gain. This type of volume control is used for both manual and automatic systems.

### AUTOMATIC VOLUME CONTROL

AUTOMATIC VOLUME CONTROL (A.V.C.) is simply a means of bleeding off some of the rectified current from the detector through a high resistance so that the d-c voltage thus built up can be applied to the r-f amplifier grids to control their gain. As signal intensity rises, more current flows in the detector circuit, and hence more voltage is applied to the grid to cut down the gain of the previous stages. So, as the signal rises and falls in strength, the A.V.C. circuit automatically regulates the amplification or volume of the receiver.

### DELAYED A.V.C.

But you won't want the A.V.C. in operation all the time. For example—suppose you're receiving a very weak signal, and the manual volume control is set at maximum output. If you still get a very low output under these conditions, A.V.C. would only make it weaker.

You can overcome this effect by using a tube with two plates, one of which handles the A.V.C. circuit. Connect this plate so that it has the same biasing voltage on it as is on the cathode. Then this voltage will have to be overcome before any rectifying

action can take place. In this way the action of A.V.C. is DELAYED until the signal strength is high enough to make A.V.C. useful.

### BY-PASS CIRCUITS

Even though you eliminate feed-back from inter-electrode capacity or coupling between input and output circuits, your high-gain amplifier can still oscillate. You need good BY-PASSING, in addition to proper shielding. This is especially true at high frequencies where even short leads may have enough inductance to produce feed-back through common coupling. And this is why the connections from by-pass condensers should be brought by SEPERATE leads to a common point on the cathode.

### SENSITIVITY, SELECTIVITY, FIDELITY

Here are the factors that determine the SENSITIVITY of a T-R-F receiver—

The number of amplifier stages, the amplification per stage, the type of detector used, and the amount of audio amplification that follows the detector.

You determine the amplification per stage by the type of tube used and the  $Q$  of the tuned circuit.

And here's what determines the SELECTIVITY of a T-R-F receiver—

The individual tuned circuits, the number of such tuned circuits, and the coupling coefficient in each stage.

At LOW frequencies, T-R-F receivers are highly selective. But at HIGH frequencies, the tuning becomes broader, since it is difficult to maintain a high  $Q$  in the tuned circuits. Thus a T-R-F receiver which JUST satisfactorily rejects signals 10 kc. off resonance at 500 kc. would not satisfactorily reject signals 10 kc. off resonance at 2,000 kc. Besides—

You'll have a lot of trouble maintaining a constant-width band-pass selectivity characteristic over a

given frequency range in the T-R-F receiver. And, you must maintain extremely accurate alinement of the TRF stages to maintain high selectivity. The SUPERHETERODYNE receiver doesn't have these disadvantages, which is why the superheterodyne is replacing the TRF receiver circuit.

Receiver FIDELITY is closely related to the over-all selectivity characteristics of the receiver. Extreme selectivity cuts down the response at high a.f. since the side band frequencies are shortened. So, you'll have to use BAND-PASS circuits to give your receiver HIGH FIDELITY. And remember, you'll have trouble maintaining a constant band width in a TRF receiver without complicated coupling circuits. Receiver fidelity is also determined by the type of detector and the frequency response characteristics of the a-f amplifier. You also have the problem of amplitude distortion to eliminate. In the case of an a-f amplifier, you have these same problems in either the T.R.F. or the SUPERHETERODYNE receiver.

### BAND SELECTION

Naval aircraft radio receivers cover a wide frequency range. To make a single coil-and-condenser combination to cover this wide range would be impracticable because of the large maximum-minimum capacity ratio required by such a condenser. And tuning this single unit would be a real headache. So—

You solve the problem by using a single condenser, but providing several coils to change the inductance for each band. This arrangement may be either of two forms. You can SWITCH from one coil to another to change frequency, or you can use PLUG-IN COILS, taking one coil out and putting in another to change frequency. The Navy receivers use both systems.

## ALINING THE T-R-F RECEIVER

The T-R-F receiver can work at maximum selectivity and sensitivity only when the individual stages of the receiver are tuned to the same frequency—ALINED—at each part of the frequency band. There are several reasons for a receiver getting out of alinement—

MECHANICAL SHOCK can change the capacity of the main tuning condensers mounted on the gang shaft. Or—

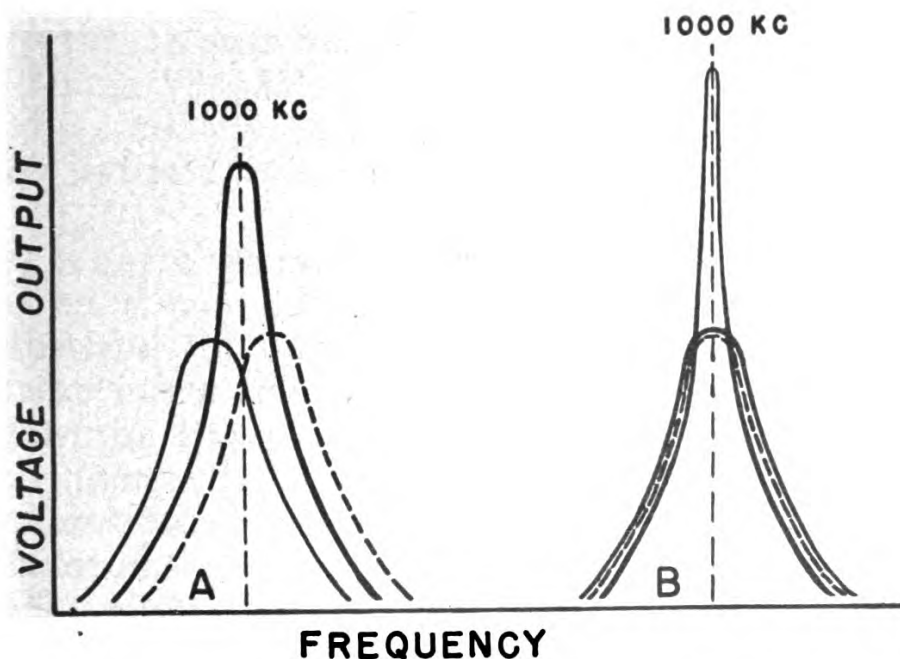


Figure 149.—Overall and stage selectivity characteristics.

CHANGES may occur in the capacity of the TRIMMER CONDENSERS used to tune stages to the same frequency in the original alinement.

You can do a better alinement job if you KNOW what effect each adjustment has on the tuned circuit of the receiver.

Each tuned circuit of a T-R-F receiver has a certain selectivity characteristic known as the STAGE SELECTIVITY. When two of these stages are used, the PRODUCT of the two curves is the OVERALL SELECTIVITY



CHARACTERISTIC. Look at figure 149 to see what is meant. In diagram *A*, you have two stage curves, showing the characteristics of two stages that differ in frequency by 20 kc. at 1,000 kc. And you have the overall graph of the output voltage obtained from an input signal of constant magnitude when the frequency of this voltage is varied around the point of 1,000 kc.

In diagram *B*, you have the same two stages tuned to 1,000 kc. exactly. Now the overall curve is much sharper or more selective, and the voltage output for a given signal input is greater. Because of this, you can determine when the stages are exactly alined by measuring the output voltage you get for a given input voltage. When the output is MAXIMUM, your receiver is alined.

The condensers for a T-R-F receiver are made so that the capacity of each condenser will match its coil at each point across the range. But it's impossible to make each condenser in a production run exactly like all the others. So you add a small adjustable TRIMMER condenser in parallel with the main condenser. This trimmer condenser can be adjusted by a screwdriver to bring the stages into alinement at any desired frequency. Actually, you usually use the trimmers to aline only the high-frequency end of the band. Once you've adjusted the trimmers, they need no further adjustment as long as the receiver stays alined.

### WANT TO ALINE ONE?

You have a receiver with two stages of r-f amplification and a plate detector, the circuit shown in figure 150. The frequency band of the receiver is 600–1,500 kc. Aline the receiver.

First of all, get your tools. You'll need a signal generator and an output meter, in addition to your regular tool kit. You can use either an a-c milli-

voltmeter connected across the speaker coil, or a d-c milliammeter connected in the detector plate circuit. Connect the signal generator to the antenna coil terminals.

If the receiver has A.V.C., turn the receiver volume control to maximum volume. Set the output of the signal generator to give a mid-scale reading on the output meter. Next—

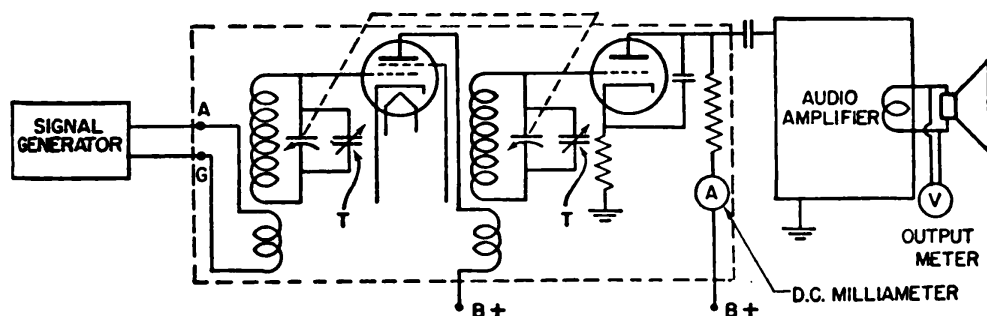


Figure 150.—Connections for aligning T-R-F receivers.

Set the signal generator at 1,500 kc. Set the receiver dial at 1,500 kc. Note the output meter reading. Adjust the trimmer condenser—*T* in figure 150—in each stage to get a maximum reading on the output meter. Now both r-f stages are tuned to 1,500 kc., and the overall characteristic is peaked at 1,500 kc. You've aligned the HIGH end of the frequency band. And now—

Set the signal generator to 600 kc. Adjust the main receiver tuning condenser to give a maximum reading on the output meter. Next you must find out whether the two r-f stages are actually at 600 kc.

However, because your receiver is in resonance, you cannot assume that both stages are in alignment at 600 kc. The maximum response only indicates that the OVERALL selectivity curve of the combined stages is at 600 kc. For example, one stage could be at 595 kc. and the other stage at 605 kc. But a simple test will tell you whether both stages are actually tuned to the same frequency.

You'll need another special tool—a TUNING WAND—to allow you to change the inductance of either tuning coil. A tuning wand is a PENCIL with one-half filled with iron filings and the other end fitted with a ring. Put the ring end near the coil, and the current produced in the ring will have the effect of REDUCING the coil inductance. Put the end of the wand containing the iron filings in the coil, and you INCREASE the inductance of the coil.

Keep this point in mind before you start the test—The overall selectivity characteristic of the receiver is the combined effect of the two stages. Shift either stage frequency and you shift this overall selectivity characteristic. Also—when both stages are tuned to the same exact frequency, the response on the output meter will be MAXIMUM. If you have any misalignment, the output readings will be below maximum. Thus, you can determine the degree of misalignment.

When you tuned the receiver to 600 kc., you peaked the signal at the resonant frequency of the overall characteristic, and you got a certain maximum output reading. Now insert the iron-filings end of the tuning wand in one coil, and increase the coil inductance. You get a new overall curve, and you shift the coil frequency. Your receiver isn't tuned to 600 kc. any longer. You can re-tune the receiver to peak the new characteristic on the 600-kc signal.

Suppose that the receiver WAS originally in alignment. You knocked out this alignment by inserting the tuning wand, and re-tuning the receiver produces a LOWER reading on the output meter. This lower reading tells you one of two things—

The two stages were ALINED originally, or—

The two stages were OUT of alignment originally, and you've knocked them FURTHER out.

You've got to find out which of the two is true.

Next, put the ring-end of the wand in the coil and tune the receiver for maximum response. If the new

output reading after re-tuning is again LESS than the reading without the wand in the coil, you know that the stages were alined originally, and you need test no further. But—

• If the new output reading after re-tuning is GREATER than the maximum reading without the wand, you know that the stages were NOT alined originally and the wand has brought them close to alinement.

In this receiver, you brought the stages into alinement by decreasing the coil inductance with the wand. You could make this alinement permanent by taking turns OFF the coil. But, since misalinement is usually caused by variation in capacity, you can bend the endmost plate of the variable condenser to reduce the overall capacity. This has the same effect as lowering the inductance. Some variable condensers have adjusting screws which are used to move the end plates in or out.

REMEMBER—you can't use the trimmer condensers to aline the low-frequency end. Why? Because you'd foul up the high-frequency alinement.

To aline the stages, you can move EITHER stage into alinement with the other stage. The stage to be moved is determined by the effect on the receiver dial calibration. You always alter the alinement in such a way as to bring in the maximum response at 600 kc. as nearly as possible on the 600-kc. dial mark.

### SUPERHETERODYNE RECEIVERS

In the SUPERHETERODYNE receiver, the frequency of the incoming signal is changed to a new radio frequency—an INTERMEDIATE frequency—by means of the HETERODYNE process. This i.f. is then amplified, and finally detected.

In figure 151 you have a block diagram for a SUPERHET. receiver.

The output of an adjustable LOCAL oscillator—the h-f oscillator—is mixed with the incoming signal in a MIXER or CONVERTER stage—the FIRST DETECTOR—to produce a beat frequency equal to the i.f. You make CW signals audible by heterodyning the signal at the second detector by the BEAT-FREQUENCY OSCILLATOR (b.f.o.) which you set to differ from the i.f. by a suitable audio frequency.

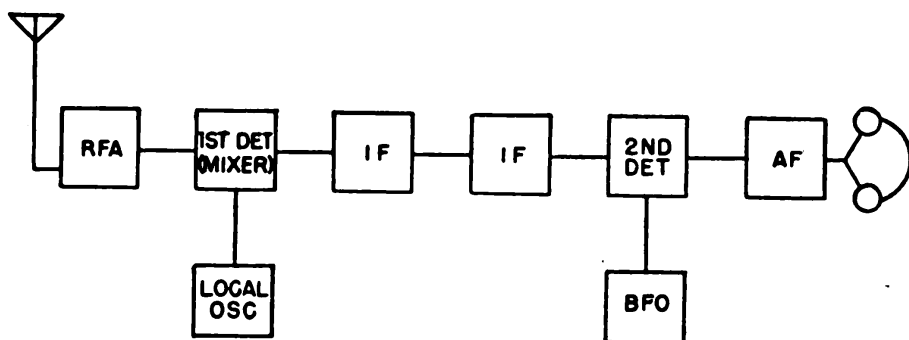


Figure 151.—Block diagram of superheterodyne receiver.

Here are some of the advantages of a superhet.—

The i.f. can be made a LOW frequency. You obtain HIGH GAIN at LOW FREQUENCIES because of the greater efficiency of tuned circuits. Thus, you can develop the same overall gain at lower frequencies with fewer amplifier stages.

Also of importance is the fact that the SELECTIVITY CHARACTERISTIC of a tuned circuit is better at LOW frequencies, since the  $Q$  of the tuned circuit is HIGHER. And—

The superhet. produces substantially CONSTANT SELECTIVITY over a given range, since all signals are amplified at the SAME FREQUENCY, no matter what the ORIGINAL frequency was. Besides—

The i-f stages in the superhet. operate at a single FIXED i.f., and so it is easier to obtain a BAND-PASS SELECTIVITY CHARACTERISTIC.

## LOCAL OSCILLATOR

In the superheterodyne, you use the LOCAL OSCILLATOR (b.f.o.) which you set to differ from the a.c. The frequency of the local oscillator must be variable across the range necessary to produce beats of i-f value with every station the receiver is designed to pick up. You usually design the local oscillator to operate above the frequency of the incoming signal by the value of the i.f. For example—

An incoming signal is at 6,000 kc., and you've chosen an i.f. of 455 kc. Then set your h-f oscillator at 6,455 kc. so that the BEAT FREQUENCY (6,455–6,000) will be 455 kc. You could also set the h-f oscillator to 5,545 kc., which would give the same frequency difference.

The OSCILLATOR FREQUENCY is determined by the capacitance and inductance of the tuned grid or plate circuit. And you change this frequency by changing the oscillator tuning capacitor. This condenser is ganged to the shaft that turns the pre-selector condenser. In this way, the oscillator frequency is always maintained above the incoming signal frequency. Since the h-f oscillator works at a frequency far different from the signal frequency, the incoming signal will have practically no effect on the stability of the h-f oscillator.

## INTERMEDIATE AMPLIFIER

The INTERMEDIATE FREQUENCY AMPLIFIER is used to amplify the i-f signals from the FIRST DETECTOR. The high  $\mu$  of screen-grid tubes makes them useful for i-f amplifier service. You always use TRANSFORMER COUPLING on i-f amplifier stages. The coupling between primary and secondary determine the band width. Each i-f transformer has a TUNED primary and a TUNED secondary, and is designed to have a HIGH L/C ratio.

You tune each section to the exact frequency required by means of screw adjustments on small mica condensers having a range of about 90 to 200 micro-microfarads. Once the receiver is alined by these condensers, no further adjustments are necessary unless the receiver gets out of alinement.

### FIRST DETECTOR

Signals from the local oscillator, as well as the desired input signal, are impressed and MIXED on the input circuit of the FIRST DETECTOR. Because of heterodyne action, the output circuit will contain an i-f signal with a frequency equal to the difference in frequencies between the oscillator and the incoming signal.

### SECOND DETECTOR

In the SECOND DETECTOR stage, i-f signals containing the modulation on the original signal are DEMODULATED to produce an AUDIBLE signal of the same frequency as the modulator frequency. You then feed this signal to the input of the AUDIO amplifier.

### HETERODYNE ACTION

In the superhet. receiver, the i-f signal is generated by HETERODYNE ACTION. Hence, if you impress two frequencies on a detector grid circuit, the output circuit would contain signals that are the SUM and the DIFFERENCE of the original frequency. For example—

If you impress two signals, one at 1,000 kc. and the other at 1,200 kc. on a detector grid, your plate circuit will contain two signals, one at  $1,200 + 1,000$ , or 2,200 kc. and the other at  $1,200 - 1,000$ , or 200 kc.

A local oscillator in the superhet. produces an r-f signal which you mix with the incoming signal frequency in the first detector or mixer. Normally, you

make the oscillator frequency 455 or 460 kc. ABOVE the incoming signal frequency. The oscillator frequency is shifted automatically to maintain this 460 kc. difference as you tune in different stations. The DIFFERENCE-FREQUENCY SIGNAL, or i-f signal, is fed to i-f amplifier stages that are fix-tuned to 460 kc. The i-f signal containing the original modulation on the carrier is amplified in these i-f stages. You then impress it on the grid of a second detector which DEMODULATES the carrier wave to produce the a-f signal.

## IMAGES

Because you get BOTH the sum and the difference frequencies in the plate circuit of the first detector, you get an IMAGE FREQUENCY which must be eliminated. Here's how an IMAGE gets into the superhet.—

You want to pick up a 1,000 kc. signal. Your LOCAL OSCILLATOR is generating at 1,460 kc., in order to produce the i-f signal at 460 kc. But, suppose—

Another station is transmitting its signal at 1,920 kc. The difference between this station's signal and your local oscillator will also be 460 kc.—the difference between 1,920 and 1,460 kc. And so two entirely different 460 kc. signals are being fed into the i-f stages, and you'll hear a distorted mixture of both.

Even the highest degree of sensitivity in the i-f stages won't eliminate the interfering station. The interference is caused by the IMAGE SIGNAL, and the frequency difference between the desired signal and the image signal is always TWICE the i-f frequency.

You also get DOUBLE RESPONSES because sum-and-difference frequencies are created in the plate circuit. For example—

Assume again that you want to pick up a 1,000-kc. signal. When you tune the receiver to 1,000 kc., you also tune the local oscillator to 1,460 kc., producing



an i-f signal at 460 kc. But, you could also receive this same station by tuning your receiver to 540 kc. or 1,000 — 460. In this case, the 1,000 kc. signal would beat against the 540 kc. oscillator signal to produce the DIFFERENCE frequency of 460 kc. So you can receive one station at TWO points.

You can get rid of both these defects—IMAGES and DOUBLE RESPONSES—by cutting down the signal strength of the image signal at the grid of the first detector. But you must use an r-f or PRE-SELECTOR STAGE ahead of the MIXER stage. Tune this pre-selector stage to the frequency of the desired signal. Thus you reduce the image-signal strength fed to the first detector grid. There's very little difference between the circuits of a pre-selector stage and the first stage of a T-R-F receiver.

### ALINEMENT OF A SUPERHET.

If your receiver develops poor sensitivity, distorted output, and general overall inefficiency, it has probably gone out of alinement. A superhet. receiver is alined properly when all i-f stages are peaked at the i-f frequency, and the FREQUENCY DIFFERENCE between the oscillator and pre-selector circuits is held constant at this i.f. across the full band.

In a superhet., aline the i-f stages first. You'll need—a SIGNAL GENERATOR to deliver a modulated signal over the required range, an OUTPUT METER calibrated in milliwatts, and an insulated ALINEMENT SCREW-DRIVER. Now you're ready to start—

First, in alining the i-f stage, you take the oscillator out of the circuit. Then connect the output lead from the signal generator through a small condenser to the grid of the first detector. Connect the ground lead to the receiver chassis. Next, adjust the signal generator to deliver a signal of the same frequency as the i-f frequency. Set the receiver gain control at maximum.

Next you adjust the small CAPACITORS in the top of the i-f transformer by using the insulated alinement screwdriver. Adjust FIRST the capacitor across the SECONDARY of the i-f transformer. At the same time, reduce the amount of input from the signal generator as the reading on the output meter increases. Then—

Adjust the capacitor across the PRIMARY of the i-f transformer, using the same procedure.

After you've alined the i-f stages, adjust the OSCILLATOR TRIMMER and the r-f PRE-SELECTOR TRIMMERS. Here's how—

Set the signal generator to produce the top frequency in the receiver band. Set the receiver dial at this same frequency. Then adjust the OSCILLATOR TRIMMER until the meter shows MAXIMUM reading. Reduce the signal generator output by steps as you adjust the oscillator trimmer until you obtain an absolute peak. Next—

Follow a similar procedure with the r-f TRIMMER in the PRE-SELECTOR stage. When both the oscillator and pre-selector stages are alined, you've completed alinement of the h-f portion of the receiver. Then—

Set the signal generator to the LOWEST frequency in the band, and tune the receiver to obtain a maximum reading on the output meter. Adjust the SERIES PADDING CONDENSER in the oscillator circuit for maximum output. While you are doing this adjusting, "rock" the receiver dial back and forth across the signal generator frequency.

After you've finished this adjustment, reset the receiver to its highest frequency, and check the settings of the oscillator and r-f trimmers for maximum output meter readings.

You use a visual alinement procedure in adjusting receivers that have the flat-top, flat-side tuning characteristic. The i-f sensitivity of this type of receiver should not vary over the desired band width

allowed in the band-pass tuning circuits of the i-f amplifier.

The superhet. principle can be incorporated in T-R-F receivers, as in the diagram of figure 152, by adding an oscillator and a mixer circuit. When this is done, the r-f amplifier in the T.R.F. becomes an i-f amplifier. Then you set this amplifier on one fre-

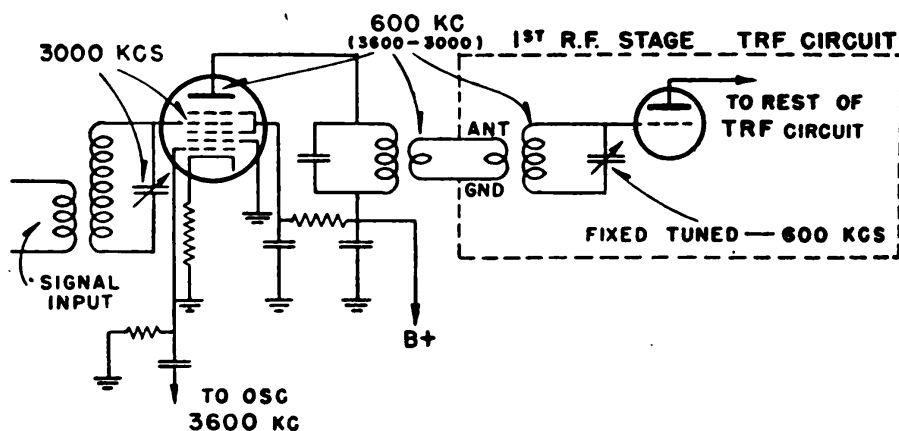


Figure 152.—T-R-F Receiver with Frequency conversion.

quency, and leave it there. The oscillator must deliver a mixer signal with a frequency which differs from that of the receiver by the frequency of the i-f amplifier. You make use of this principle in h-f adaptors in order to reduce the ultra-high-frequencies that normally are above the receiver range down to the frequency of the r-f amplifier.



## CHAPTER II

### MICROPHONES

#### THE SOUND GOES IN HERE . . . .

The SOUND WAVES that you produce as you talk or sing into a microphone are converted by the mechanism of the microphone into ELECTRICAL IMPULSES that the radio transmitter and receiver can handle. The microphone diaphragm vibrates at the same frequency of the spoken word, and in turn produces an a-c voltage of the same frequency.

#### SENSITIVITY

The ratio of ELECTRICAL OUTPUT to SOUND INPUT gives you the SENSITIVITY of the microphone. Sensitivity varies widely between different types of microphones, and even between models of a single type. The character and tones of voices cause variations in the sensitivity of a microphone, and even the distance of the speaker away from the microphone will affect the microphone output. The output decreases almost directly as the square of the distance from sound source to microphone.

## FREQUENCY RESPONSE

The FREQUENCY RESPONSE is a gauge of the ability of a microphone to convert a range of SOUND frequencies into a.c. With FIXED SOUND INTENSITY at the microphone, the electrical output may vary widely as the SOUND FREQUENCY varies. For clear speech transmission, however, you need only a limited frequency range. You can get a faithful reproduction of speech from a microphone whose output is relatively uniform over a range of 100 to 4,000 cycles.

If a microphone shows very SMALL variation in response between its upper and lower frequency limits, you say that it has FLAT FREQUENCY RESPONSE.

There are several types of microphones—CARBON, CRYSTAL, CONDENSER, and VELOCITY or RIBBON types.

### CARBON MICROPHONE

In addition to being the most commonly used type, the carbon microphone is the sturdiest, and gives the largest output for a given input. Figure 153 shows the principal parts of a SINGLE-BUTTON CARBON MICROPHONE.

This microphone operates on the principle of VARYING RESISTANCE between carbon granules as the PRESSURE on the GRANULES is varied. The sound waves created by your voice, for example, cause a metal diaphragm in the microphone to move back and forth a tiny distance. This travel of the diaphragm causes the carbon granules to be packed tighter or more loosely in the brass cup containing them. When the diaphragm is pressed inward by a sound wave, the carbon granules are forced tighter together, and the electrical resistance of the granules is LOWERED. As the diaphragm moves outward again, the granules are packed together LESS tightly, and resistance INCREASES.

These alternate increases and drops in resistance

cause a fluctuation in the microphone current being fed from a 6-volt battery to the carbon granule assembly. You feed these current fluctuations through the primary winding of the microphone transformer, and INDUCE a voltage in the secondary of the transformer. The frequency of this induced voltage is equal to the frequency of the sound wave from your throat or violin.

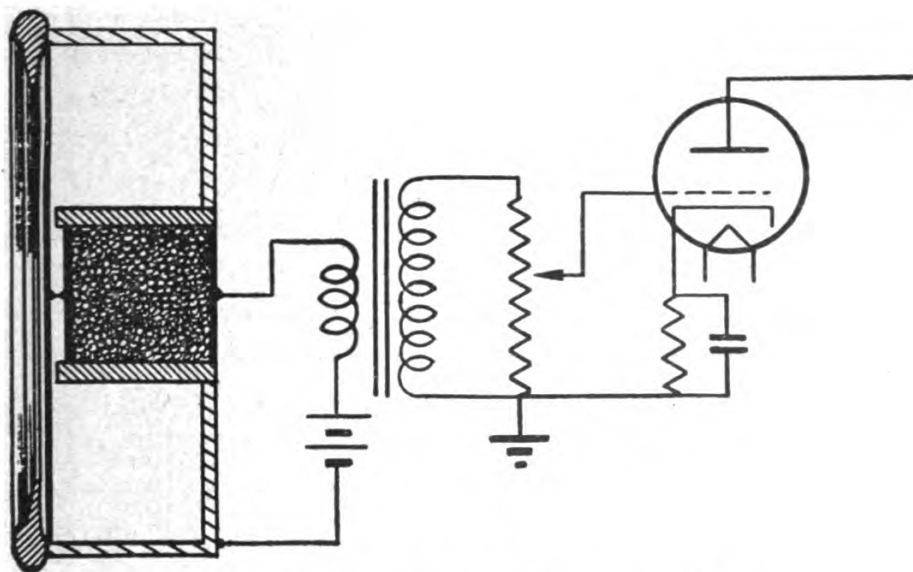


Figure 153.—Single-button carbon microphone.

You get a large electrical output from the carbon microphone, but the frequency response is not very uniform. However, the carbon microphone has a frequency response that is sufficiently good for reproduction of sounds in the speech-frequency band. You can IMPROVE the FREQUENCY RESPONSE by using a very light, tight-stretched diaphragm, but you'll REDUCE the microphone SENSITIVITY.

A SINGLE-BUTTON carbon microphone normally has a SENSITIVITY RANGE of about 0.1 to 0.3 volt output across 50 to 100 ohms resistance in the microphone transformer primary. With a step-up transformer, you'll get a peak voltage of about 3 to 8 volts across 100,000 ohms resistance in the secondary.

The DOUBLE-BUTTON carbon microphone is a refined type, in which a thin, lightweight diaphragm is set between TWO cups containing carbon granules. Thus the vibration of the diaphragm by sound waves causes the granules in one cup to be COMPRESSED, while the pressure on the second cup of granules is REDUCED. Thus, the current through one side INCREASES while the current through the other cup DROPS.

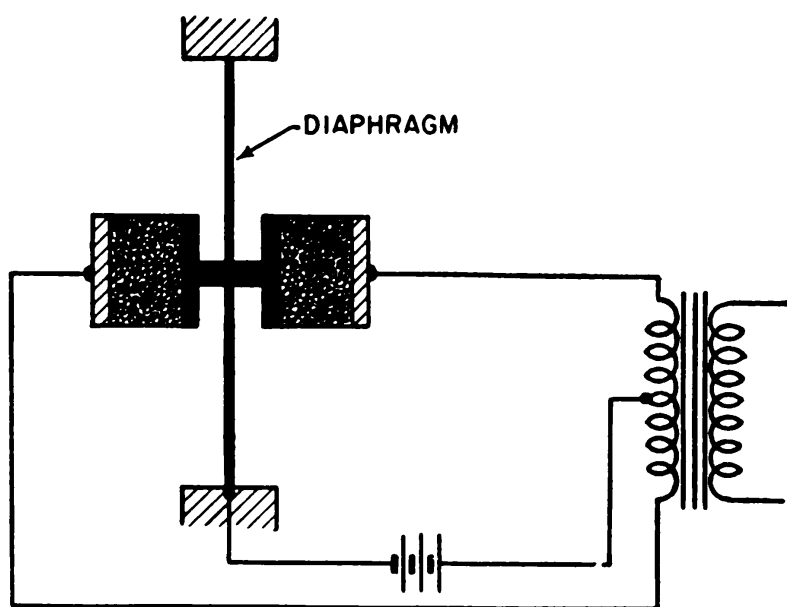


Figure 154.—Double-button carbon microphone.

You use a microphone transformer that has a center-tap primary, with the connections rigged so that the currents from the two carbon cups flow through the transformer in opposite directions. Look at figure 154 for the diagram.

Here's what happens—

A current INCREASE in the UPPER half of the PRIMARY induces a SECONDARY voltage in the same direction as would be produced by a current DROP in the LOWER half of the PRIMARY. And when the diaphragm moves in the opposite direction, the reverse occurs.

A double-button carbon microphone is much less sensitive than a single-button type. The output voltage of the double-button unit is about 0.02 to 0.07 volt through 200 ohms. You'll usually get a peak output voltage of 0.4 to 0.5 volt across 100,000 ohms with the double-button microphone operated through the usual push-pull input transformer.

The chief advantage of the double-button over the single button type? By using push-pull operation, you eliminate the even harmonies, and obtain better frequency response.

The field produced by the current through ONE half of the primary exactly neutralized the field set up by the current through the OTHER half of the primary winding. So, you get no magnetizing effect by the steady value of current through the iron core of the microphone transformer.

You make this cancellation even more accurate by adjusting the current through the two buttons to an equal value. You do this by connecting variable resistors in each outside leg of the microphone circuit.

Carbon-granule microphones may develop these troubles—A large current will produce tiny arcs between carbon particles, causing the granules to stick together, or PACK. Packing lowers the sensitivity of the carbon buttons to slight changes, hence cuts down the variation in resistance of the microphone, affecting its sensitivity to sounds. And, the tiny arcs in the carbon granules cause scratchy microphone noises.

### CRYSTAL MICROPHONE

The CRYSTAL MICROPHONE makes use of a phenomenon called PIEZO-ELECTRIC EFFECT. Here's what this is—

Some crystals generate a tiny electrical voltage when they are squeezed and quickly released. In a CRYSTAL microphone, you make the sound waves of your voice or your piccolo beat against a quartz crys-



tal or Rochelle salts cemented together so as to be electrically in series. See figure 155. The alternate pressure and release of the crystals by the sound waves generate small voltages. The VOLTAGES are QUITE SMALL, but the FREQUENCY RESPONSE over the selected range is UNIFORM.

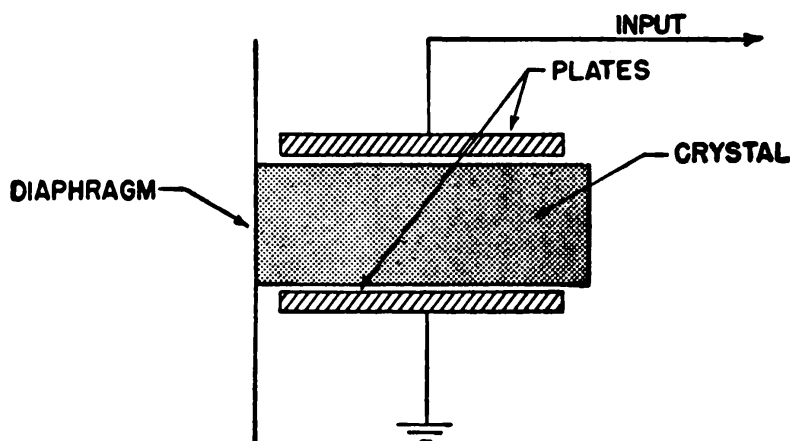


Figure 155.—Crystal microphone.

Because the voltage is small, you usually use several stages of amplification with the crystal microphone.

A variation of the crystal microphone makes use of a metal diaphragm cemented to the crystal so that vibrations of the diaphragm stress the crystal. These stresses generate voltages by piezo-electric effect. This type of microphone produces a much larger electrical output than the simple crystal microphone, but its frequency response is limited by the stiffness and inertia of the metal diaphragm.

The output voltage of a crystal microphone is usually 0.01 to 0.03 volt. The length of cable connecting the microphone to the first amplifier directly affects the sensitivity of the microphone. The longer the cable, the lower is the microphone sensitivity.

## CONDENSER MICROPHONE

In the CONDENSER MICROPHONE, you have a thick and a thin plate set close to each other, and with a d-c voltage impressed on the two plates. The thick plate is fixed. The thin plate acts as a diaphragm, and vibrates back and forth when a sound wave strikes it. As the thin plate travels back and forth, the space between the two plates changes, and the capacity between the two plates is changed. Figure 156 gives you the circuit diagram for this microphone.

As the capacity between the plates changes with variations in sound, the condenser charging current

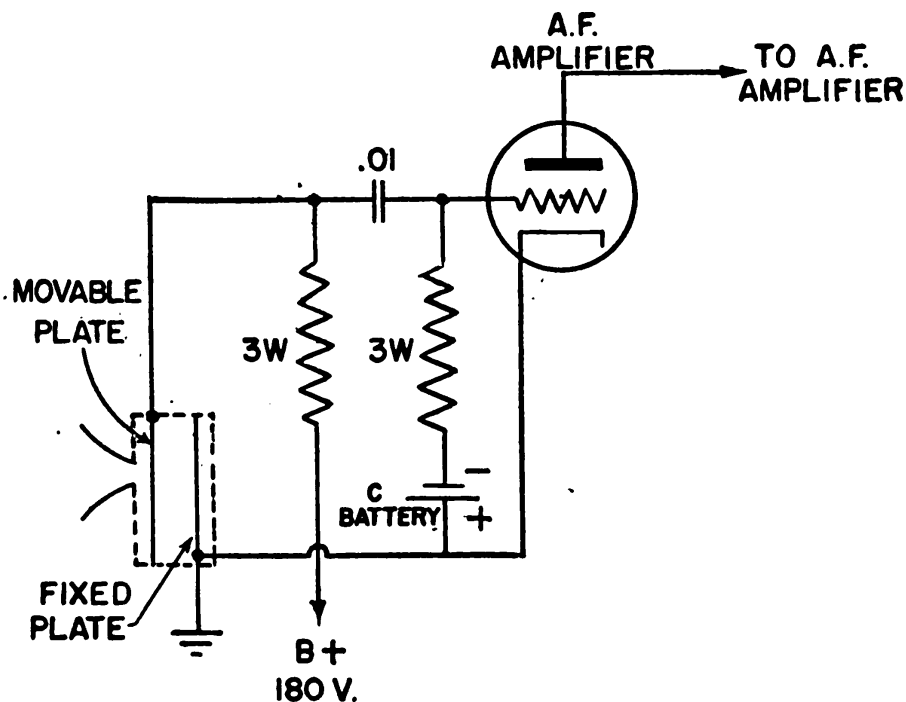


Figure 156.—Condenser microphone.

changes. These variations in current produce a voltage drop across the resistor. You connect the resistor across the grid circuit so that these small voltage variations across the resistor are amplified in the tube.

The condenser microphone has several advantages. It is relatively stable, its response across a wide frequency range is constant. But—

It has low sensitivity, and the microphone must be close to the amplifier. Long leads increase the overall capacity of the microphone circuit, and reduce the sensitivity. Normally, the voltage output of the condenser microphone is quite low, about 1/50 to 1/100 that of a double-button carbon microphone.

### VELOCITY OR RIBBON MICROPHONE

The heart of the VELOCITY MICROPHONE is a thin, flexible aluminum ribbon. That's why this type of microphone is often called the RIBBON MICROPHONE. The sound element is shown in figure 157.

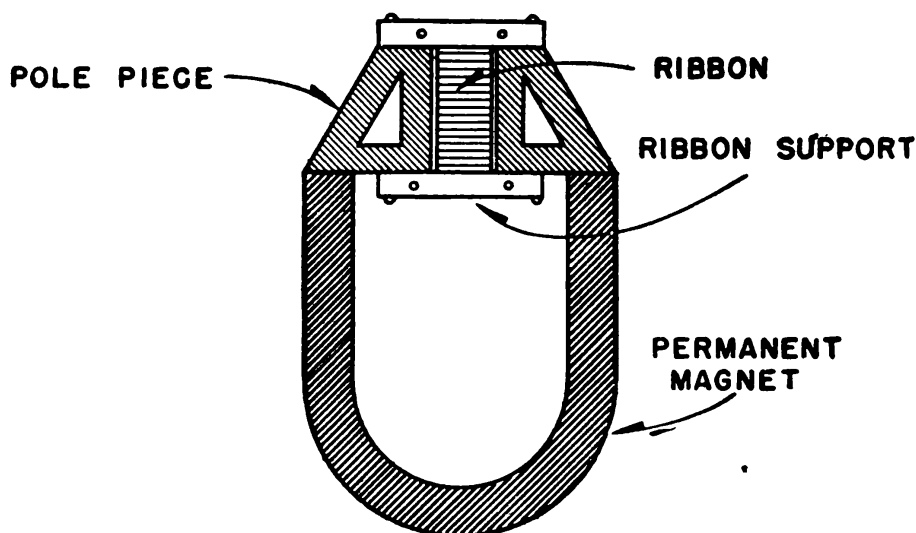


Figure 157.—Velocity or ribbon microphone.

The aluminum ribbon is suspended between the poles of a powerful permanent magnet. When sound waves strike this ribbon, the ribbon vibrates back and forth, cutting the magnetic field of the magnet. This cutting of magnetic lines of force generates an alternating current in the ribbon. You then feed this a.c. to the tube of an a-f amplifier through a step-up transformer.

The primary of this transformer matches the impedance at the microphone, and the secondary matches the impedance at the transmission cable to the amplifier input.

The ribbon microphone responds to the AIR VELOCITY in the sound wave, whereas the carbon grain microphone responds to the SOUND PRESSURE. The ribbon microphone has DIRECTIONAL pick-up qualities, since sounds that strike it in a plane flat to the microphone aren't picked up as well as sounds that strike it at an angle. You frequently use the ribbon microphone for localized pick-up of sounds from a particular direction.

This microphone is a delicate mechanism, and isn't able to handle relatively large input pick-ups. You usually connect it through two or more stages of amplification to get the desired signal level. The output of a ribbon microphone, with correct transformer coupling, is 0.03 to 0.05 volt.

The main advantages of the ribbon microphone are its directional pick-up and its excellent frequency response over a wide range. Its output impedance is low, too. But, it cannot be used close to the sound source nor out-of-doors where wind will strike it.

### DYNAMIC MICROPHONE

In the DYNAMIC MICROPHONE a lightweight voice coil is rigidly attached to a diaphragm. The coil is placed between the poles of a permanent magnet, as in figure 158. The sound waves strike the diaphragm, making it vibrate. As the diaphragm vibrates, it moves the coil back-and-forth between the magnet poles, cutting magnetic lines of force and generating an alternating voltage whose FREQUENCY is proportional to that of the sound wave, and whose AMPLITUDE is proportional to the sound PRESSURE.

The dynamic microphone is usually built with high-impedance output so that it will work directly into the grid of an amplifier tube. If you have to use a VERY LONG connecting cable, you'll want to use a low-impedance dynamic microphone, with a step-up transformer at the end of the cable.

Here are the advantages—

The dynamic microphone can be handled during operation without producing unwanted sounds in its output. It is dependable, requires no battery supply, has excellent frequency response between 20 and 9,000 cycles, is light in weight, and is not affected by atmospheric variations. But—

Unless you speak directly at the diaphragm at a

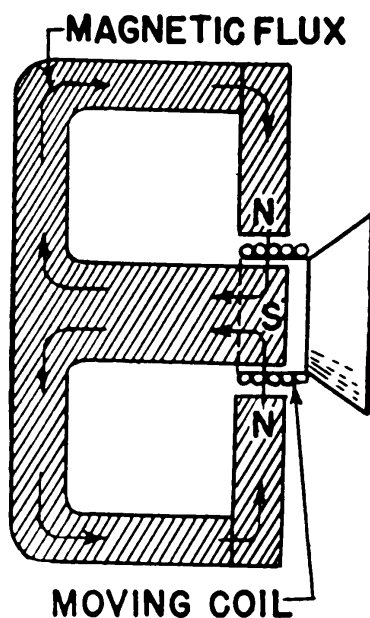


Figure 158.—Dynamic microphone.

90° angle, the microphone fails to pick up frequencies above 1,000 cycles very well. In effect, the dynamic microphone is highly DIRECTIONAL to high-frequency sounds, and NON-DIRECTIONAL to low-frequency sounds. This defect is compensated for by the use of baffles and by proper aiming of the microphone.



## CHAPTER 12

### OSCILLOSCOPES

#### MAKING ELECTRONS DRAW PICTURES

You can save yourself a lot of time and headaches on the job by using the CATHODE-RAY OSCILLOSCOPE to analyze and trouble-shoot circuits. And what you'll learn about the oscilloscope in this chapter is only the beginning. Once you've gotten acquainted and familiar with this instrument, you can use your own brains and ingenuity to find new uses for it in radio work. Every day, somebody dredges up a new use or a new job for the cathode-ray oscilloscope.

#### IT'S A VACUUM TUBE

Fundamentally, the CATHODE-RAY OSCILLOSCOPE is a vacuum tube. A stream of electrons is driven off the hot metal cathode and sent flowing to the plate. BUT you are NOT interested in the current which flows from plate to cathode as electrons move from cathode to plate. (That old wrong-guesser, Ben Franklin, is in again!) This time you're interested in the ELECTRONS themselves. You're going to make them draw pictures for you.

But the cathode-ray tube doesn't look like any other vacuum tube you ever saw in a radio transmitter or receiver. It looks more like a potato masher with the tube base in the head of the handle, and the screen in the enlarged masher end.

The electrons that leap out of the white-hot metal cathode are attracted to the positive anode. The tube structure is designed so that the electrons form into a stream, like water from a fine nozzle, and rush at a high rate of speed through the vacuum to a special screen that FLUORESCES or glows when electrons strike it. This beam of electrons follows a straight line, unless it is diverted or bent by an electric or magnetic field, or by striking particles of gas in the tube. You might say that the beam of electrons is like a beam of light from a searchlight, EXCEPT that the electron beam can be attracted or repelled by positive or negative objects, and is affected by magnetic fields.

The electron beam is too short in wave-length to be visible to the naked eye. So you use the fluorescence phenomenon of materials known as PHOSPHORS to make the electrons produce a picture or line that you can see.

### WHAT'S INSIDE

Inside the potato-masher-shaped glass envelope of a cathode-ray oscilloscope tube, you'll find many elements in addition to the familiar cathode and anode. First, look at figure 159, which is a schematic sketch of the inside of one of these tubes.

The cathode *K* is indirectly heated, and has an electron-emitting substance on its end only, so that electrons are driven off chiefly in the direction of the screen at the far end of the tube. The grid *G* is a cylinder with a hole in the center of one end. This hole is lined up with the cathode and the center of the screen.

The tube in figure 159 uses ELECTROSTATIC FOCUSING, which is done by the two anodes  $P_1$  and  $P_2$ . These anodes are at different positive potentials from the cathode. Both anodes are cylindrical, with aiming holes in their ends to beam the electrons toward the screen. Anode  $P_2$  is usually larger in diameter than anode  $P_1$ , and both are larger than the cylindrical grid. You'll come to the SECOND type of focusing—MAGNETIC FOCUSING—later.

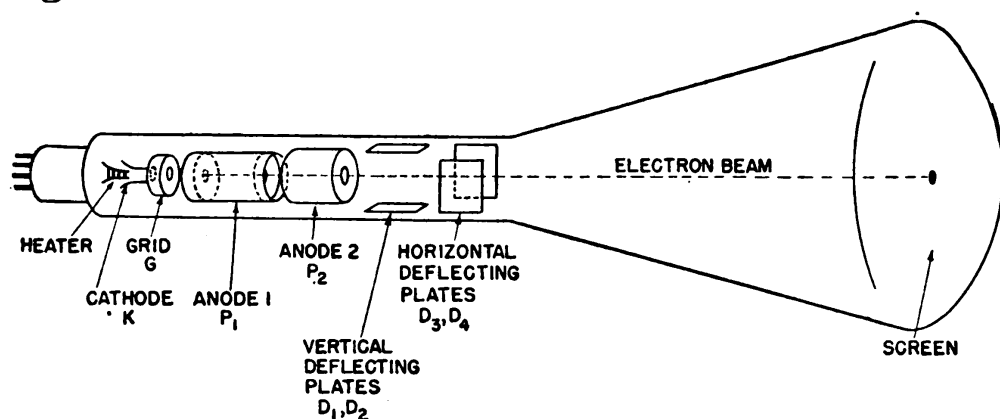


Figure 159.—Structure of cathode-ray tube.

The grid is negative to the cathode in order to control the flow of electrons towards the screen. Anodes 1 and 2 are at positive potentials with respect to the cathode, and anode 1, which is closer to the cathode, is a little bit less positive than anode 2. These anodes draw the electrons forward from the cathode, and give them an extra shove towards the screen.

The difference in potential of the two anodes focuses the electron stream into a narrow beam which comes to a point when it strikes the screen. This part of the tube is the ELECTRON GUN, and is used in ALL cathode ray tubes.

The voltage on anode 2 determines the speed of the electrons as they pass the anode. For example, if you impress 6,000 volts positive to the cathode on anode 2, the electrons will leave anode 2 at about



1,800 inches per microsecond, or 25,000 miles per second.

The elements of a cathode-ray tube that give it its most useful characteristics are the two pairs of DEFLECTING PLATES—the vertical plates  $D_1$  and  $D_2$ , and the horizontal plates  $D_3$ , and  $D_4$ , in figure 159. These plates can change or bend the direction of the electron beam as it passes from cathode to screen.

The weight of the beam of electrons is so small that you can assume it to be zero, hence it takes very little force to change the direction of the beam. Even at high frequencies, the electron beam can be bent or pushed around without a measurable error due to inertia. AND, even though the electrons are shaped into a beam or ray, they are still negative bits of electricity, and can be influenced and attracted by electrically-charged plates and objects. Thus—

- Suppose you put a POSITIVE charge on one of the VERTICAL plates  $D_1$  with respect to  $D_2$ . The electron beam will be bent or attracted towards  $D_1$ . The amount of this bending will depend upon the size and arrangement of  $D_1$  and  $D_2$ , the difference in voltage between the two plates, and the speed of the electrons towards the screen.

Likewise, by charging one of the HORIZONTAL plates  $D_3$  more positive than the other horizontal plate  $D_4$ , you can bend the electron beam towards  $D_3$ . Of course, you could make  $D_2$  positive to  $D_1$ , and  $D_4$  positive to  $D_3$ , and bend the electron beam into another corner of the screen. Once the beam has passed beyond the two pairs of deflection plates, it proceeds in a straight path to the screen. No bending of the beam occurs after the electrons are past the plates.

The electrons in the beam flow in ONE direction, at high speed, hence they have the characteristics of an electric current, and can be acted on by a MAGNETIC field. If you exposed the beam to any magnetic

field, the direction of the beam would be bent by the forces of the magnetic field established around the field AND by the magnetic lines of force from the outside magnetic system.

You can see the difference in effect between ELECTROSTATIC and MAGNETIC influences on the beam. For example, you can secure vertical deflection of the beam ELECTROSTATICALLY by charging plates ABOVE and BENEATH the beam. But vertical deflection magnetically is obtained only with a magnetic field crossing the beam HORIZONTALLY, or by having magnets at either SIDE of the beam.

### ELECTROSTATIC FOCUSING

The cathode ray tube in figure 160 has its electron gun focused by ELECTROSTATIC FOCUSING. The volt-

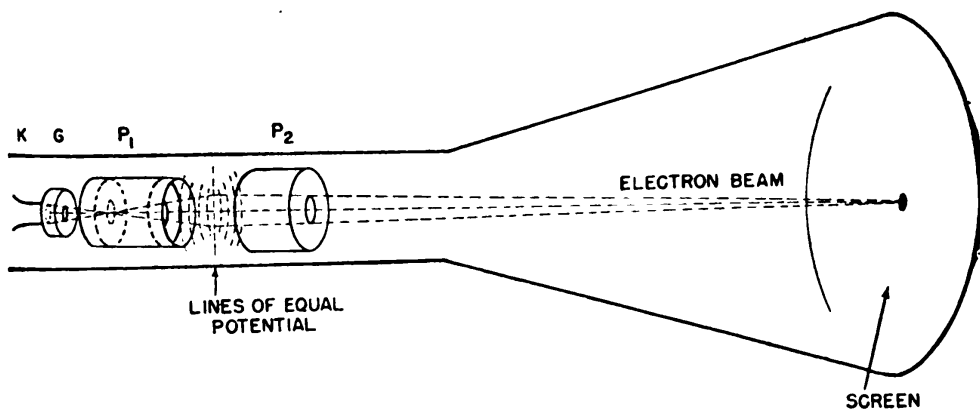


Figure 160.—Electrostatic focusing elements in a cathode ray tube.

age differences between anodes  $P_1$  and  $P_2$  produce an electric field between the two. The LINES OF EQUAL POTENTIAL between  $P_1$  and  $P_2$  are indicated on the drawing. You will notice that these lines of equal potential take a shape that is quite similar to the shape of a double convex glass lens such as is used in focusing light rays in a camera or a microscope. And that electrical “lens” does just that—it FOCUSES the DIVERGING electron beam from the cathode into a CONVERGING beam that narrows down to focus as a

pin-point of light on the fluorescent screen. You FOCUS this type of tube by varying the potential of  $P_1$  with respect to  $P_2$

### MAGNETIC FOCUSING

By wrapping a coil of wire around the neck of a cathode ray tube outside the glass envelope, and so that the axis of the coil coincides with the axis of the tube, you can focus the electron beam MAGNETICALLY. You feed d.c. in the proper direction through the coil, and vary the current to vary the degree of focus. The arrangement of the coil is shown in figure 161.

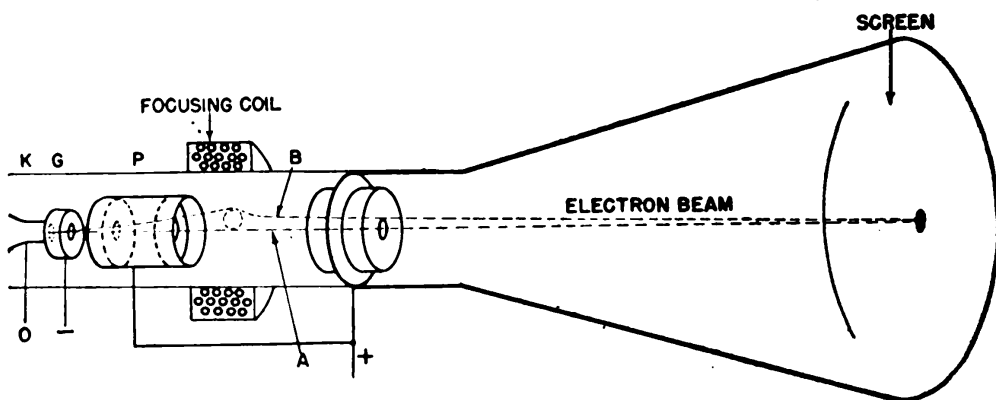


Figure 161.—Magnetic focusing device for cathode ray tube.

To see clearly how MAGNETIC FOCUSING works, suppose there are TWO beams of electrons,  $A$  and  $B$  in figure 161, passing through the tube. Stream  $A$  follows the axis of the magnet coil, while stream  $B$  wanders off course as it leaves the anode  $P$ .

You might consider the two streams of electrons to be developing magnetic fields of their own. The magnetic field developed by stream  $B$  produces a reaction among the various magnetic fields to develop a twisting motion in divergent beams such as  $B$ . The combination of these twisting and forward motions makes the divergent beam follow a cork-screw path while in the field of influence of the magnetic focusing coil.

As you adjust the strength of the magnetic field, you reach a point where such diverging beams as  $B$  are made to converge in focus on the screen. The greatest advantages of magnetic focusing are that it is done by a coil wrapped around the outside of the tube, and that it does not require adjustment of high voltages to focus the beam.

### ELECTROSTATIC DEFLECTING SYSTEMS

You'll find either MAGNETIC or ELECTROSTATIC DEFLECTING SYSTEMS used in cathode ray tubes.

Look back at figure 159 to how the two pairs of deflector plates for ELECTROSTATIC DEFLECTION are set up in the tube. Since the two plates  $D_1$  and  $D_2$  control VERTICAL bending of the electron beam, they are called VERTICAL DEFLECTION PLATES, even though they are set in a HORIZONTAL plane. For the same reason, the two plates  $D_3$  and  $D_4$  are HORIZONTAL DEFLECTION PLATES, in spite of being set VERTICALLY.

If you put the same voltage on all four plates, the electron beam is acted on by four equal and opposite electrostatic forces, and should pass through the dead center that is established by the dotted lines from the opposite corners of each pair of deflecting plates, and go on to strike the center of the fluorescent screen. Next—

If you put continuously varying voltages on the vertical plates  $D_1$  and  $D_2$ , and put other varying voltages on the horizontal plates  $D_3$  and  $D_4$ , the beam would be bent in a varying cycle, and the focus point of the beam on the screen would move from point to point, to trace a curve. Thus, if you put an a.c. on the vertical plates, and put a voltage that had a constant time rate of change on the horizontal plates, your electron beam would draw the trace of an a-c wave on the screen.

You can arrange the circuits so that as soon as the beam has moved from left to right on the screen, it

will jump back to the starting point again, and would redraw the trace as long as the tube connections remain the same. This left-to-right movement of the beam and its focus spot is the SWEEP, and the number of sweeps per second gives you the SWEEP FREQUENCY. Sometimes you make the sweeps vertical from bottom to top.

Make the SWEEP FREQUENCY equal to the VERTICAL frequency, and the trace of the beam will be the wave form that you applied to the vertical plates. With some types of cathode ray tubes, you can obtain traces of frequencies from only a few cycles per second up to cycles of a few hundred thousand cycles per second. Frequencies above 200 kc. require special high-voltage cathode ray tubes.

### MAGNETIC DEFLECTING SYSTEMS

The magnetic deflecting system of a cathode ray tube shown in figure 162, consists of TWO PAIRS of COILS, arranged so that one pair has its axis at right angles to the other pair of coils, and both pairs are at right angles to the axis of the tube and the line of flight of the electrons. When you apply current to the pair of coils that have a HORIZONTAL axis, you'll cause VERTICAL DEFLECTION of the electron beam. Apply current to the other pair of coils, set in the VERTICAL AXIS, and you produce HORIZONTAL DEFLECTION.

By applying varying voltages to the two pairs of coils, you get a trace of a curve on the screen, just as you got with ELECTROSTATIC deflection. But there's this difference—

Unless you have a great deal of power available, your deflection coils will have to carry a good many turns of wire, and the inductance of the coils will be quite large. Since coils with high inductance have different impedances at different frequencies, and since this impedance rises with higher frequencies,

the magnetic deflection tube is not satisfactory for use with a wide range of frequencies.

The deflection mechanism of the magnetic system is much sturdier and more resistant to damage and maladjustment by shock and rough handling than the electrostatic mechanism. The magnetic apparatus is on a collar that is slipped over the outside of

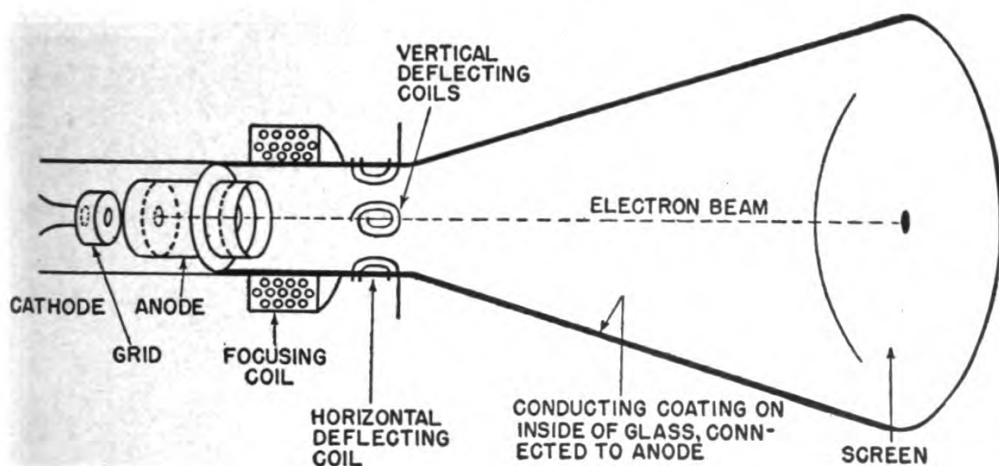


Figure 162.—Magnetic focusing and deflection coils in cathode ray tube.

the tube, and can be readily replaced or adjusted. But the electrostatic mechanism is sealed inside the tube, and is easily thrown out of adjustment by rough handling of the tube.

The electron gun in BOTH types of tubes is delicate and easily damaged by rough treatment.

### SHIELDING

Since the beam of electrons in the cathode ray tube is deflected by either magnetic or electrostatic fields, you must carefully shield the tube from the earth's magnetic field and electrical fields created by apparatus near the tube. You want the electron beam to be acted on only by the controlled currents and voltages you apply to the deflection plates.

The inner surface of the tube glass envelope is usually coated with a graphite mixture which is con-

nected to the second anode  $P_2$ . This coating shields the electron gun and deflector portions of the tube from the effects of nearby electrical fields. Connecting the shielding to the second anode puts a relatively high POSITIVE potential on the shielding compared to the cathode. You usually connect up the electrical system of a cathode ray tube in such a way as to GROUND the second anode. Thus the shielding is at GROUND POTENTIAL. This is the POSITIVE side of the d-c system, hence the CATHODE is at high NEGATIVE voltage with respect to ground.

To shield the tube from the earth's magnetic field, you surround the tube assembly with a soft iron cylinder. Ground this cylinder in order to avoid the formation of magnetic fields on the surface of the cylinder.

### THE SCREEN

The fluorescent screen of the cathode ray tube is made by coating the inside of the large tube end with a PHOSPHOR or fluorescing mixture. When this mixture is struck by the electron beam, the phosphor glows, or gives off light.

Phosphors can be compounded to glow for a short, medium or long period, and different types of work require different times of persistence.

Be careful not to turn the electron beam intensity up too high, or you may damage the phosphors on the screen. Also, don't let the beam play on one spot or over the same trace too long, or you'll burn the screen. Bright sunlight isn't good for the screens, so protect the tube from direct sunlight.

The phosphors tend to flake off the tube slightly, so be careful not to shake or vibrate the tube. And be careful not to turn the tube socket-end down, since this will drop flakes of phosphors into the electrical connections at the base.

## JOB'S FOR THE OSCILLOSCOPE

Radio repairmen have a great regard for the cathode ray oscilloscope, and they can justify its high cost by the large number of fairly expensive instruments whose jobs can be done better by the oscilloscope. Here are JUST A FEW JOBS you can check-up with the oscilloscope—

1. Wave form studied on generators of all types.
2. Alinement of resonant circuits.
3. Measurement of modulation percentage.
4. Distortion measurements.
5. Check receiver for dead spots.
6. Current and voltage surges.
7. Vacuum tube characteristics.
8. Comparison of wave shapes.
9. Measurement of voltage and current values.
10. Radio direction finding.
11. Frequency comparisons.
12. Phase determination.

And hundreds of others. The better you get to know the cathode ray oscilloscope, the more jobs you'll find to use it for.





How Well Do You Know—

## **ADVANCED WORK IN AIRCRAFT RADIO**



# QUIZ

## CHAPTER I

### KIRCHOFF'S LAWS

1. Write out, IN YOUR OWN words, a statement of each of Kirchoff's two laws.
2. At a three-wire junction, 10 amps flow in over lead #1, and 6 amps flow out over lead #2. What is the current in lead #3, and in which direction?
3. (a) What polarity sign do you give a RISE in potential?  
(b) A drop in polarity?  
(c) A battery emf?  
(d) A battery IR value?
4. You solve a problem by using Kirchoff's Laws, but get an answer of  $-1.3$  amps. Why? How can you get a positive answer? What will the positive answer be?
5. (a) Current enters a resistor through the (plus) (minus) end.  
(b) Current leaves a battery through the (plus) (minus) end.
6. You have a generator, a battery and a bank of lamps in a parallel circuit. The emf of the generator is 32 v., with 0.3 ohm internal resistance. The battery has an emf of 24 v., with 0.2 ohm internal resistance. The resistance of the lamp bank is 125 ohms. Draw the circuit diagram, and find (1) Terminal voltage of battery, (2) Terminal voltage of generator, (3) Current through lamp bank, (4) Current through battery circuit, and (5) Current supplied by generator.
7. (a) How much current flows through a battery that is floating on the line?  
(b) A battery is floating on the line, and has an emf of 6 volts. What is the terminal voltage of the generator in this circuit?
8. What is the voltage across each voltage-dropping resistor in a series circuit proportional to?

9. (a) What does a bleeder resistor do?  
(b) What percentage of the full-load current is usually bleeder current?

## CHAPTER 2

### MEASUREMENT INSTRUMENTS

1. Current to be measured by a galvanometer flows through what part of the galvanometer?
2. Since the galvanometer is designed to measure small currents, what do you connect across the terminals to make it measure large currents?
3. A galvanometer in a circuit reads 3 ma., and has 75 ohms resistance in it. You have a 1-ohm shunt across its terminals. What total current flows in the entire circuit?
4. You have a 6-volt voltmeter, with an internal resistance of 500 ohms. You know you've got to measure a voltage that is between 25 and 30 volts. What resistance should you add in series to the voltmeter circuit?
5. (a) To measure a low resistance accurately, how do you connect the voltmeter?  
(b) To measure a high resistance accurately by voltmeter-ammeter method, how do you connect the voltmeter?
6. The Wheatstone bridge is used to measure what?
7. The Wheatstone bridge has how many resistors? How many are fixed, how many variable, how many unknown?
8. In connecting up a Wheatstone bridge, what precaution must you take to avoid putting extra resistance in the circuit?
9. You make a megger by adding what equipment to an ohmmeter circuit?
10. What voltage can a megger usually impress on the circuit under test?
11. What prevents a d-c meter from operating on an a-c circuit?
12. Can you use a-c meters on d-c circuits?
13. (a) When you heat the junction of a thermocouple, what is the electrical result?

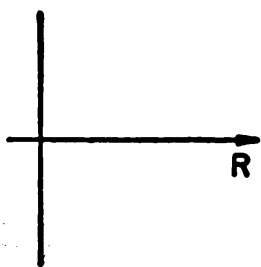
- (b) How is a variation of this result used by electricians?
14. What do you use a copper-oxide rectifier for?
  15. You are handed a resistance of unknown value and told to find its value. By using a Wheatstone bridge, you find that the galvanometer registers zero when  $R_1 = 5$  ohms,  $R_2 = 3$  ohms, and  $R_3 = 6$  ohms. What is the resistance of  $R_x$  in ohms?
  16. In the vacuum-tube voltmeter, you use a charge in (grid) (plate) (cathode) (suppressor) current to measure the applied voltage.

## CHAPTER 3

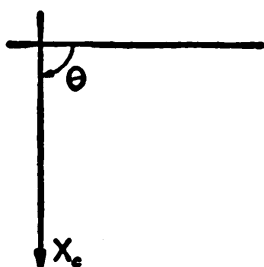
### THEORY OF A.C.

1. If you chart the voltage induced in a loop conductor as it turns  $360^\circ$  in a magnetic field, what type of curve will you get?
2. A two-pole generator rotating at 3,600 rpm produces 60-cycle current. A 12-pole generator would rotate how many rpm to generate 60-cycle current?
3. A certain a-c generator gives a peak voltage of 550 volts. What is its effective voltage?
4. An aircraft is flying due north at 150 miles per hour. The wind is blowing 30 mph from 50 degrees south of west. Draw the vector diagram and find the resultant speed and direction of the aircraft's course.
5. You want to add algebraically the output from two a-c generators. What must be the phase-relation of the two generators?
6. Generator *A* leads generator *B* by  $30^\circ$ . How can you add their outputs?
7. What three factors of an a.c. do you need to know to find the average power?
8. Each of these vector diagrams indicates a circuit which contains (a) resistance, (b) inductance, (c) capacitance, (d) reactance, or (e) some combination of two of these. Identify

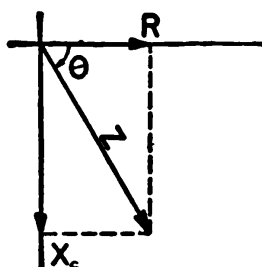
the piece of electrical gear which is indicated by each vector diagram.



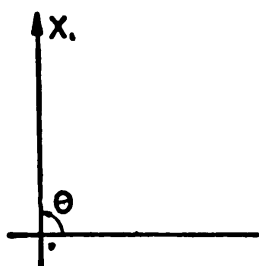
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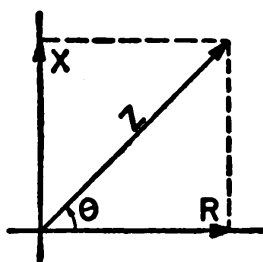
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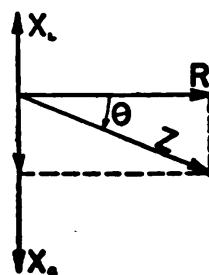
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④



⑤



⑥

9. (a) When is a circuit resonant?  
(b) In a resonant circuit, what is the relationship of inductance to capacitance?
10. Is the total current through a parallel circuit a maximum or a minimum when the circuit is in resonance? Which is it for a series circuit in resonance?
11. What are the two types of three-phase connections for a generator or motor?
12. How many degrees apart are the voltages of a 3-phase alternator supplying a balanced load?
13. (a) The line current in a delta-connected system is equal to how many times the phase current?  
(b) The line voltage of a wye-connected system is how many times the phase voltage?
14. Here are some formulas for electrical properties. What does each formula bring to mind?

- (a)  $2\pi fL$ ; (b)  $EI \cos \theta$ ; (c)  $E^2/R$ ; (d)  $PE/I$ ; (e)  $\frac{1}{2\pi\sqrt{fC}}$ ;  
 (f)  $R_1 R_2 \sqrt{R_1^2 + R_2^2}$ ; (g)  $\sqrt{R^2 + (X_L - X_C)^2}$ ;  
 (h)  $\frac{\text{Output}}{\text{Input}} \times 100$ .

## CHAPTER 4

### VACUUM TUBES

1. In a vacuum tube, electrons flow from the cathode, which is (positive) (negative), to the plate, which is (positive) (negative).
2. Why does center-tapping the return circuit from the plate and grid to the transformer help reduce hum?
3. What determines the saturation current of a vacuum tube?
4. When you have the negative alternation of a.c. on the plate, in which direction is electron flow?
5. In a triode, the point at which all  $I_p$  stops flowing is called (zero point) (dead point) (cut-off) (null).
6. How can you hold the triode  $e_g$  to fixed negative voltage with respect to  $e_k$ ?
7. To determine tube performance, you use what three ratios?
8. What determines the  $\mu$  of a tube?
9. What two resistances in a tube make up the internal plate resistance?
10. The micro-mho is a unit of what?
11. Feedback is worst between (grid and plate) (plate and cathode) (grid and cathode) (grid, plate, and cathode)?
12. What part would you insert in the grid-to-plate circuit to neutralize inter-electrode capacity?
13. In a tetrode, secondary emission causes a (rise) (dip) (leveling-off) in the tube characteristic curve.
14. What does the suppressor grid in a pentode do to reduce the effect of secondary emission?
15. In a variable- $\mu$  tube, the  $\mu$  is varied by varying the (inter-electrode resistance) (negative grid-bias) (plate capacitance) (dipolar multitrode conductance).
16. The beam-forming plates of a beam power tube operate at (plate) (cathode) (ground) (suppressor-grid) potential.



## CHAPTER 5

### AMPLIFIERS

1. In a Class B amplifier, plate current flows (all the time) (half a cycle) (none of the time) (after the tube cuts-off).
2. In a Class C amplifier, plate current is (maximum) (zero) (half-value) when no a-c grid voltage is applied.
3. Which class of amplifier do you use to avoid distortion? Where distortion doesn't matter?
4. How do you increase the gain of a voltage amplifier tube? What radio parts do you use to do this?
5. What three items make up input impedance in a tube?
6. What are the three types of couplings? Which is used most?
7. What happens to the whole power output of a resistance-coupled amplifier?
8. What type of coupling do you usually use with a push-pull circuit?
9. The amplification curve for a transformer coupling drops off at high and at low frequencies. Why? (two reasons).
10. Why do you have less hum in a push-pull circuit?
11. How do you prevent "motorboating"?
12. What is the tube arrangement of a Class B power amplifier?
13. In inverse feedback, where do you feed part of the output voltage?
14. Why use shunt feed?
15. What are three types of distortion?
16. What is Q?
17. The two tubes of a push-pull amplifier act in (parallel) (series) ( $90^\circ$  out of phase) (unison).

## CHAPTER 6

### POWER SUPPLIES

1. When do you have maximum voltage across a diode in an a-c circuit? What is this value of voltage called?
2. What portion of full-load voltage must each half of the transformer secondary carry in a full-wave rectifier?
3. What two advantages do gas-filled power tubes have?

4. What three precautions must you take in operating a gas-filled power tube?
5. Loosening or tightening the bolts on a copper-oxide rectifier has what effect?
6. What two units of equipment make up a filter circuit?
7. Which type of filter would you use with a rectifier supplying large amounts of current — choke-input or condenser-input?
8. A swinging choke has (large) (small) inductance at low current, and (large) (small) inductance at maximum current.
9. Resonance occurs in a 60-cycle filter circuit when  $L + C$  equals (0.613) (348) (3.14) (1.77) henries. Which?
10. You need a voltage divider system for a transmitter to supply the following voltages and load currents
  1. 1500 v. at 150 ma.
  2. 1000 v. at 80 ma.
  3. 500 v. at 60 ma.
  4. 200 v. at 20 ma.
  5. -125 v. at 0 ma.

Bleeder current = 10 ma.

Draw the diagram, find the value of each resistor, and determine the total voltage required from the source.
11. How many armature windings does a dynamotor have?
12. What type of power supply gives you d-c voltage that has no fluctuations?

## CHAPTER 7

### TRANSMITTERS

1. What is a "buffer" stage, and what does it do?
2. What does the oscillator circuit give you?
3. What two parts make up a tank circuit? How are they connected?
4. How much power do you have to keep adding to an oscillator to keep it operating?
5. What do you adjust to change the frequency of a Hartley oscillator? To change the frequency of a Colpitts oscillator?

6. What type of feedback is used in the Hartley oscillator?  
In the Colpitts oscillator?
7. What is the advantage of electron-coupling for oscillators?
8. What type of keying do you get by opening and closing the plate and grid circuits at the same instants?
9. With blocked-grid keying, where do you apply the negative grid-bias voltage? How large should this voltage be?
10. What is a time-constant?
11. How broad a band of interference do key-clicks produce?
12. What are two methods of eliminating key-clicks?

## CHAPTER 8

### MODULATION

1. In MCW (modulated continuous wave), which wave do you key?
2. (a) Under what conditions will you develop maximum variation of the carrier wave modulation?  
(b) What percentage of modulation is this?
3. What undesirable factors do you get by over-modulating?
4. At peak modulation upswing for 100% modulation, what is the instantaneous power value?
5. The speech amplifier for plate modulation usually operates as Class (A), (B), (C). Which?
6. Carrier amplitude rises and drops at the same frequency as what voltage?
7. What type of coupling is usually used in plate modulators?
8. In a grid-bias modulator, what voltage is used to vary the grid bias?
9. With suppressor modulation, you vary the bias on what element of the vacuum tube?
10. Cathode modulation is a combination of what two systems of modulation?
11. You have a 2500-kc. r-f signal, which you modulate with a 1000-cycle audio signal. What frequencies are your two side-bands?
12. At 100% modulation, total power will be  $(2/3)$  (50%) (the same)  $(1\frac{1}{2})$  the power in the unmodulated carrier wave.

## CHAPTER 9

### WAVES AND ANTENNAS

1. (a) Radio waves are (electrostatic) (electromagnetic) (thermionic) waves.  
(b) They are composed of what two types of fields?
2. (a) What is the ionosphere composed of?  
(b) What effect does the ionosphere have on radio waves?
3. At very high frequencies, long-range transmission is (better) (impossible) (poor) due to the presence of the ionosphere.
4. When there are two components of a wave and they are exactly out of phase, the field strength of the signals will be (maximum) (zero) (doubled) (half).
5. Is the path of travel of v-h-f waves normally more similar to the path of ordinary radio waves or light rays? Which?
6. What ratio gives you the impedance of an antenna?
7. To what is the electromagnetic field around an antenna proportional?
8. The voltage in an antenna is (in phase) ( $90^\circ$  out of phase) ( $180^\circ$  out of phase) with the current.
9. What is the difference between a Hertz and a Marconi antenna?
10. You want to erect a Hertz antenna to operate on 8,270 kc. How long should it be if the antenna is to operate at its fundamental wavelength?
11. What is the difference between a current-fed and a voltage-fed antenna?
12. You have an antenna that is too long to work on a certain frequency. What do you insert in the antenna to have the effect of shortening it?

## CHAPTER 10

### RECEIVERS

1. In a receiver you work the diode detectors at (high) (low) (very high) (zero) resistance.
2. (a) What are the two general types of plate detectors?  
(b) What is the output of each type proportional to?

3. Where does rectification take place in the grid-leak detector?
4. What is the path of plate-circuit energy in the regenerative receiver?
5. What kind of feed-back control do you use in a regenerative circuit that uses triodes?
6. What is the advantage of regeneration?
7. What do you add to a regenerative circuit to make it super-regenerative?
8. How do you eliminate feed-back in a TRF amplifier?
9. In an a-f amplifier you (do) (do not) adjust input voltage to control gain, but in an r-f amplifier you (do) (do not) adjust input voltage to control gain.
10. High selectivity of a TRF receiver depends on what?
11. What do you use a tuning wand for?
12. Misalignment of a TRF is usually caused by variations in (resistance) (inductance) (capacity) (conductance).
13. What's wrong with alining the low-frequency end of a TRF by adjusting the trimmer condensers?
14. The sensitivity of a superhet. is practically constant across the range because signals are amplified at (geometric) (constant) (three) (inverse) frequencies.
15. What determines the oscillator frequency of a superhet.?
16. Which stage of a superhet produces the audible-frequency signals?
17. You have a 1500 kc. signal and a 1750 kc. signal on the detector of a superhet. What will be the frequencies of the two signals on the plate?
18. At what stage in a superhet do you cut down signal strength to get rid of images and double responses?
19. In alining a superhet, do you aline the (v-h-f) (r-f) (i-f) (r-a-f) stage first.
20. Why does a TRF tune broad at high frequencies?

## CHAPTER 11

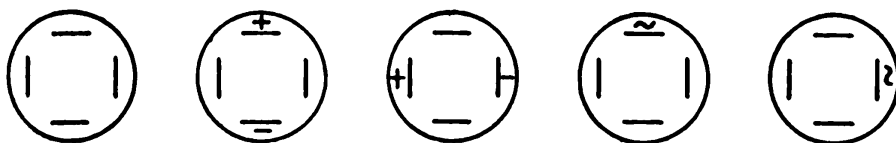
### MICROPHONES

1. What ratio gives you the sensitivity of a microphone?
2. What is the principle of operation of the carbon microphone?
3. (a) In the condenser microphone, sound waves have what effect on the two diaphragm plates?  
(b) What does this effect do?
4. How is the a.c. generated in a ribbon microphone?
5. In the dynamic microphone, the a-c voltage generated by the voice coil has a frequency proportional to the sound (wave) (pressure) and an amplitude proportional to the sound (wave) (pressure).
6. What two materials make good crystals for crystal microphones?

## CHAPTER 12

### OSCILLOSCOPES

1. In an oscilloscope, the stream of electrons can be deflected by (the weight of the electrons) (the voltage of the cathode) (magnetic fields) (the phosphors).
2. (a) If you use electrostatic focusing, you can get horizontal deflection of the electron beam by charging plates (above and below) (to right and left of) the beam.  
(b) If you use magnetic focusing, you can get vertical deflection of the electron beam by charging magnets (above and below) (to right and left of) the beam.
3. In an oscilloscope, you have the following conditions of electrical charge on the deflector plates. Where would you expect the focal point to be on the screen in each case.



4. What two conditions will cause damage to the screen?



# ANSWERS TO QUIZ

## CHAPTER 1

### KIRCHOFF'S LAWS

1. Check your statements with page 1 of this manual.
2. Four amps. flowing out over lead #3.
3. (a) Plus; (b) Minus; (c) Plus; (d) Minus.
4. (a) You assumed a wrong direction for current flow.  
(b) Reverse the current-flow arrows.  
(c)  $+ 1.3$  amps.
5. (a) Plus; (b) Minus.
6. (a)  $E_b = 23.2$  v.; (b)  $E_g = 30.75$  v.; (c)  $I_L = 0.2172$  a.;  
(d)  $I_b = 3.97$  a.; (e)  $I_g = 4.18$  a.
7. (a) None; (b) 6 v.
8. The resistance of the voltage-dropping resistor.
9. (a) Stabilizes the voltage at the other resistor taps.  
(b) 5 to 10 percent.

## CHAPTER 2

### MEASUREMENT INSTRUMENTS

1. The movable armature coil.
2. Shunt.
3.  $(75 \times 3) + 3 = 228$  ma.
4. 4,000 ohms.
5. (a) Directly across the resistance only.  
(b) Across the resistance AND the ammeter.
6. Resistance.
7. (a) Four; (b) Two; (c) One; (d) One.
8. Keep all contact points bright and clean.
9. Hand-cranked generator.
10. Usually 500 volts.
11. The alternations or reversals of current flow in a.c.



12. Yes, but not accurately. And, if the meter has a copper-oxide rectifier, you may burn it out.
13. (a) A current will flow across the cold junction.  
(b) The hot junction is subjected to a current. A voltage can be measured across the cold junction.
14. To rectify a.c. to d.c.
15.  $R_x = 10$  ohms.
16. Plate.

## CHAPTER 3

### THEORY OF A.C.

1. Sine curve.
2. 600 rpm.
3. 388 volts.
4. 147 mph or a course  $6^\circ 20'$  east of due north.
5. They must be in phase.
6. By vectors.
7. Average current, average voltage, and the phase angle.
8. (a) Resistance only.  
(b) Capacitance only.  
(c) Resistance and capacitance.  
(d) Inductance only.  
(e) Resistance and inductance.  
(f) Resistance, inductance, and capacitance.
9. (a) When its resultant current is in phase with its line voltage.  
(b) The inductance is equal to the capacitance and lagging by  $180^\circ$ .
10. (a) Minimum. (b) Maximum.
11. Delta and Wye.
12.  $120^\circ$ .
13. (a) Three. (b)  $\sqrt{3}$ .
14. (a) Inductive reactance; (b) polyphase power; (c) power; (d) power factor; (e) resonant frequency of a circuit; (f) total resistance; (g) impedance; (h) efficiency.

## CHAPTER 4

### VACUUM TUBES

1. Negative, positive.
2. The center tap is at the average potential of the whole filament, hence there are no variations in electron flow.
3. The maximum value of  $I_p$  for maximum  $E_f$ .
4. There is no electron flow.
5. Cut-off.
6. Bias the grid.
7. (a) Voltage amplification factor; (b) Mutual conductance; (c) Internal plate resistance.
8. The placement of the cathode, plate, and grid in relation to each other in the tube.
9. The resistance of the space charge and the resistance of the negative grid charge to the flow of electrons from cathode to plate.
10. Mutual conductance.
11. Grid and plate.
12. Variable condenser.
13. Dip.
14. It drives the secondary electrons back to the plate.
15. Negative grid-bias.
16. Cathode.

## CHAPTER 5

### AMPLIFIERS

1. Half a cycle.
2. Zero.
3. Class A; classes A, B, or C.
4. Increase the load resistance. Use a large value plate resistor and grid resistor.
5. Capacitance between grid and cathode, resistance due to time of travel between cathode and grid, and the resistance caused by using the cathode lead for both input and output circuits.

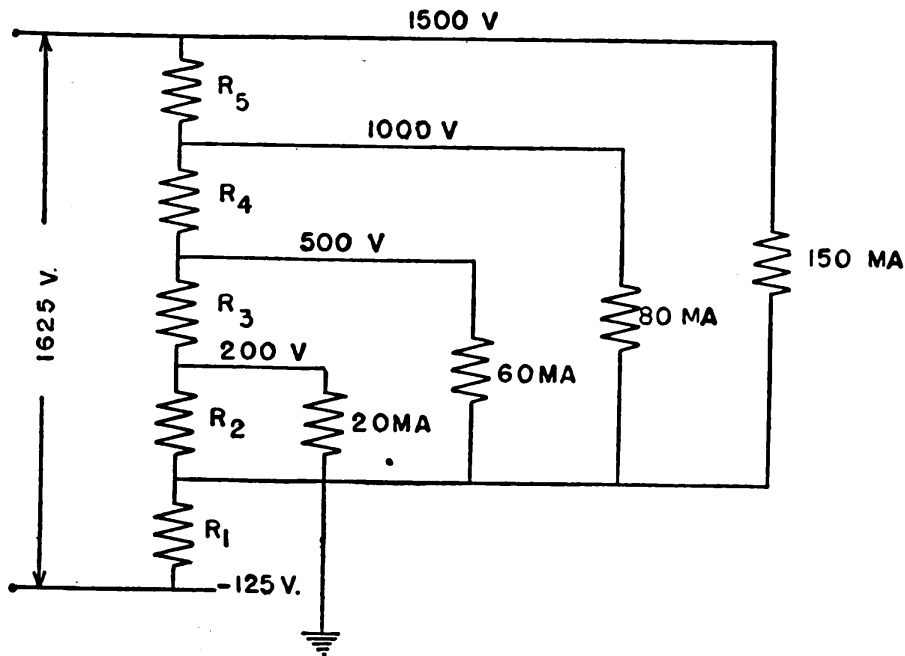
6. (a) Resistance, transformer, impedance; (b) Resistance.
7. It's used up in the load resistor.
8. Transformer coupling.
9. (a) At high frequencies, leakage inductance and the effective secondary capacitance of the transformer cut-down amplification.  
(b) At low frequencies, the transformer primary has a low reactance.
10. The hum currents in the two halves of the primary cancel out each other.
11. Use fillers in the voltage supply leads to each tube so that the signal currents won't stray into the voltage supply circuit.
12. Two tubes in push-pull, biased so that the plate current is practically zero when no signal voltage is on the grid.
13. Back to the input of the same tube.
14. To avoid running the d-c plate current through the transformer primary.
15. Frequency, phase, and amplitude or nonlinear.
16. Ratio of coil reactance  $L$  to coil resistance  $R$ .
17. Series.

## CHAPTER 6

### POWER SUPPLIES

1. (a) On the negative loop of the a-c alternation, when the plate is negative to the cathode.  
(b) Inverse peak voltage.
2. The full-load voltage.
3. (a) Constant voltage drop at all operating currents.  
(b) Low power losses.
4. (a) Be sure the tube is heated up before you apply the plate voltage.  
(b) Never exceed the rated inverse-peak voltage to the tube.  
(c) Be sure the cathode is at proper operating temperature.
5. Changes the resistance.
6. An inductance and a capacitance.

7. Choke-input filter.
8. Large. Small.
9. 1.77 henries.
10. Here's the voltage divider diagram.



And here's the solution:

$$E_t = 1500 + 125 = 1625 \text{ v.}$$

$$I_t = 150 + 80 + 60 + 20 + 10 = 320 \text{ ma.}$$

$$R_1 = \frac{125}{0.32} = 391 \Omega$$

$$R_2 = \frac{200}{0.01} = 20,000 \Omega$$

$$R_3 = \frac{500-200}{0.03} = 10,000 \Omega$$

$$R_4 = \frac{1000-500}{0.09} = 5,555 \Omega$$

$$R_5 = \frac{1500-1000}{0.17} = 2,940 \Omega$$

11. Two; the motor armature winding and the generator armature winding.
12. Glow-discharge tubes.

## CHAPTER 7

### TRANSMITTERS

1. An amplifier stage between the antenna and the oscillator. The buffer prevents load-variations from affecting the oscillator frequency.
2. It gives you a-c power from the d-c supply at the desired frequency.
3. A coil and a condenser, connected in a closed series circuit.
4. Only enough to make up the heat loss of the oscillator.
5. (a) Inductance coil.  
(b) The number of turns on the tank coil.
6. (a) Magnetic feed back.  
(b) Capacity feedback.
7. Reduction of the frequency instability caused by variations in load.
8. Cathode keying.
9. To the control or suppressor grid. Large enough to block out the r-f grid voltage.
10. The length of time it takes to charge or discharge a condenser through a resistance.
11. Usually all over the frequency band.
12. (a) The choke-and-condenser filter, and (b) the use of keying tubes.

## CHAPTER 8

### MODULATION

1. Carrier.
2. (a) When the carrier drops to zero and rises to twice its value in one cycle.  
(b) 100%.
3. Distortion and unwanted harmonics.
4. Four times the unmodulated value.
5. Class B.
6. Audio voltage.
7. Transformer coupling.

- 9. Audio voltage.
- 9. Suppressor grid.
- 10. Grid bias and plate modulation systems.
- 11. 2499 and 2501 kc.
- 12.  $1\frac{1}{2}$  times.

## CHAPTER 9

### WAVES AND ANTENNAS

1. (a) Electromagnetic.  
(b) Electric and magnetic.
2. (a) Free electrons.  
(b) Reflects the waves back to earth.
3. Impossible.
4. Zero.
5. Light waves.
6. The ratio of load resistance to applied power.
7. The current in the antenna.
8.  $180^\circ$  out of phase.
9. Hertz antenna has a length approximately half the transmitting wave-length. Marconi antenna is about one-quarter wave-length.
10. Since  $L = \frac{468}{f}$ , where  $f$  is in MEGACYCLES,  

$$L = \frac{468 \times 1000}{8270} = 56.6 \text{ ft.}$$
11. The transmitter output is fed to the point of maximum current on a current-fed antenna, and to the point of maximum voltage on a voltage-fed antenna.
12. Capacity.

## CHAPTER 10

### RECEIVERS

1. Very high.
2. (a) Square-law and linear.  
(b) The square-law detector develops an output proportional to the square of the amplitude; the linear detector develops an output proportional to the amplitude of the input voltage.
3. In the grid circuit.
4. This energy is fed back to the grid circuit to reinforce the original signal amplitude.
5. Tickler coil in the plate circuit.
6. It increases the sharpness of tuning and amplification.
7. A quench oscillator.
8. By using screen-grid tubes.
9. Do; Do not.
10. The accurate alinement of the TRF stages.
11. To change the inductance of tuning coils when you aline a TRF receiver.
12. Capacity.
13. You throw the high-frequency end out of alinement.
14. Constant.
15. The capacitance and inductance of the tuned grid or plate circuit.
16. Second detector.
17. 250 and 3250 kc.
18. At the first-detector grid.
19. The last i-f stage.
20. It's hard to maintain a high  $Q$  in the tuned circuits of TRF.

## CHAPTER 11

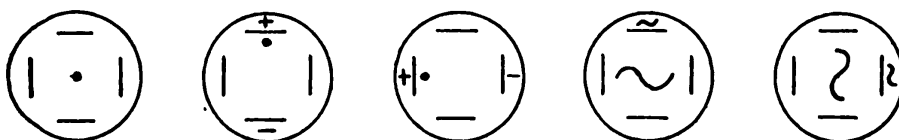
### MICROPHONES

1. Electrical output to sound input.
2. Pressure on the carbons varies the resistance of the carbons.
3. (a) Move them back and forth.  
(b) Changes the capacitance of the microphone.
4. By the aluminum ribbon cutting magnetic lines of force as it travels back and forth with sound waves.
5. Wave, pressure.
6. Quartz or Rochelle salts.

## CHAPTER 12

### OSCILLOSCOPES

1. Magnetic fields.
2. (a) To right and left.  
(b) To right and left.
- 3.



4. (a) Allowing the electron beam to strike one spot on the screen for too long a time, and  
(b) Allowing the direct rays of the sun to strike the screen.













